 ond stage eliminated all random failures, since the circumstances of this mishap required a failure to have occurred during the specific 14-minute period (ten minutes during which the transmitters were off, plus four minutes of tube warm-up time) without teleme- try. The third stage consisted of identifying the subset of single failures from the second stage that could lead to extended loss (hours to days) of downlink. The fourth stage was focused on the subset of the third-stage failures [B-4] that could be correlated with the Pressurization Sequence, which included several commands and activities that were being executed for the first time during the mission. Those failures that survived through the fourth stage were then examined with respect to supporting test data, analyses and failure history. Specific tests and analyses were identified and performed to validate or invalidate postulated scenarios. This process permitted the Board to classify the failures as to the most probable cause and potential causes. As a result of these studies, analyses and tests, the Board was led to three principal conclusions: . First Principal Conclusion Despite extensive analysis of the circumstances surrounding the mission failure of the Mars Observer spacecraft, the Board was unable to find clear and conclusive evidence pointing to a particular scenario as the “smoking gun.” Most of the failure scenarios were determined to be implausible or extremely unlikely. The Board was, however, unable to eliminate several failure scenarios. From these remaining scenarios, the Board concluded through a process of elimination that the most probable cause of the loss of downlink from the Mars Observer was a massive failure of the pressurization side of the propulsion system. The Board also concluded that the most probable cause of that failure was the unintended mixing of nitrogen tetroxide (NTO) and monomethyl hydrazine (MMH) in the titanium tubing on the pressurization side of the propulsion system. This mixing was believed by the Board to have been enabled by significant NTO migration through check valves during the eleven-month cruise phase from Earth to Mars. This conclusion is sup- ported (but not proven) by NTO transport-rate data acquired by JPL, by NTO/MMH reac- tion simulations performed by NRL, and by NTO/MMH mixing tests performed by AFPL. Second Principal Conclusion The Board concluded that the Mars Observer spacecraft design is generally sound. The investigation did, however, identify issues (some unrelated to this failure) that should be addressed and corrected prior to any flight of the same or derivative-design spacecraft. [B-5] Third Principal Conclusion The Board concluded that, although the result was a very capable spacecraft, the orga- nization and procedural “system” that developed Mars Observer failed in several areas. In particular, the system failed to react properly to a program that had changed radically from the program that was originally envisioned. Too much reliance was placed on the heritage of spacecraft hardware, software, and procedures, especially since the Mars Observer mission was fundamentally different from the missions of the satellites from which the heritage was derived. The complementary strengths of JPL and Martin Marietta

EXPLORING THE UNKNOWN 473 Astro Space (formerly RCA Astro-Electronics and General Electric Astro-Space Division) were not used by NASA as effectively as they should have been. Secondary Conclusions In addition to its assessment of the most probable failure presented earlier, the Board found that the following failures must also be considered as potential causes of the loss of downlink: Electrical Power System failure resulting from a regulated power bus short circuit. Regulator failure resulting in NTO and/or MMH tank over-pressurization and rupture. Ejection of a NASA Standard Initiator at high velocity from a pyro valve, punc- turing the MMH tank or causing severe damage to some other spacecraft system. The Board was generally impressed with the spacecraft that was developed for the Mars Observer mission. However, considering the potential for reflight of an identical spacecraft, or the use of derivative designs or hardware in spacecraft currently in devel- opment or planned for future similar mission requirements, a number of specific con- cerns were noted: [B-6] Propulsion System Inappropriate isolation mechanisms between fuel and oxidizer for an inter- planetary mission. Lack of post-assembly procedures for verifying cleanliness and proper func- tioning of the propellant pressurization system. Current lack of understanding of the differences in pyro-initiator character- istics between European Space Agency initiators and NASA Standard Initiators. Inadequate thermal instrumentation, control, and modeling for the mission profile. Electrical Power System Potential power bus short circuit susceptibility, due to improper assembly, sin- gle component failure, or insulation failure. Command and Data Handling System Critical redundancy control functions can be disabled by a single part failure or logic upset. Redundant crystal oscillator (RXO) can lose one of its two outputs without remedy of fault protection. The actual state of the backup oscillator in the RXO is not available in telemetry. Software/Fault Protection A top-down audit of fault protection requirements, implementation, and val- idation is needed.

 Systems Engineering/Flight Rules The flight system should be qualified and capable of providing insight into critical mission events. An example of this would be the availability of teleme- try during critical events. The flight system should be allowed to maintain attitude control during crit- ical operations. If any rebuild or modification of the spacecraft is anticipated, the documen- tation should be updated to reflect the as-built/as-flown configuration. The Board noted that the Mars Observer that was built departed significantly from the guiding principles originally established for the program, yet the acquisition and management strategy remained unchanged. The role of JPL in this fixed-price procurement was, at best, cum- bersome, and did not appear to make the most effective use of the unique resource represent- ed [B-7] by JPL. In any event, the use of a firm, fixed-price contract was inappropriate to the effort as it finally evolved. The original philosophy of minor modifications to a commercial pro- duction-line spacecraft was retained throughout the program. The result was reliance on design and component heritage qualification that was inappropriate for the mission. Examples of this reliance were the failure to qualify the traveling wave tube amplifiers for pyro firing shock; the design of the propulsion system; and the use of a fault-management software package that was not fully understood. The Board also noted that the discipline and documentation culture asso- ciated with, and appropriate for, commercial production-line spacecraft is basically incompati- ble with the discipline and documentation required for a one-of-a-kind spacecraft designed for a complex mission. Mars Observer was not a production-line spacecraft. While the Board can find no direct linkage between the mishap and these systemic weaknesses observed in the Mars Observer program as it evolved over the years, these weaknesses, nevertheless, remain a significant concern for future programs. The Board would like to express its appreciation for the support provided to the inves- tigation by the six technical teams, the other NRL and AFPL personnel who supported it, the NASA representatives, the JPL Project Team and Investigation Board, and the MMAS Technical Teams. Document II-41 Document title: Office of Space Science, NASA, “Final Environmental Impact Statement for the Cassini Mission," June 1995. Source: NASA Historical Reference Collection, History Office, NASA Headquarters, Washington, D.C. Document II-42 Document title: Office of Space Science, NASA, “Supplemental Environmental Impact Statement for the Cassini Mission," June 1997.

EXPLORING THE UNKNOWN 475 Source: NASA Historical Reference Collection, History Office, NASA Headquarters, Washington, D.C. In compliance with the National Environmental Policy Act, NASA must issue an Environmental Impact Statement for every spacecraft launch it conducts. Inner solar system probes, whose systems operate using solar power, generally have been approved readily. Spacecraft that travel greater dis- tances, however, cannot depend on the sun but instead use radioactive materials for power. Such mis- sions have been the focus of substantial public opposition before launch due to fear that a launch failure of a spacecraft containing radioactive materials could devastate the environment and life on Earth. These documents contain NASA's analysis of the potential effects on Earth of a catastrophe involving the plutonium-laden Cassini spacecraft during either launch or passage by Earth en route to its final destination, Saturn. The low probabilities of devastating consequences allowed the launch to proceed, despite intense public protests. [cover page] Document II-41 Final Environmental Impact Statement for the Cassini Mission Solar System Exploration Division Office of Space Science National Aeronautics and Space Administration Washington, DC 20546 June 1995 [v] EXECUTIVE SUMMARY This Final Environmental Impact Statement (FEIS) has been prepared in accordance with the National Environmental Policy Act of 1969 (NEPA) (42 U.S.C. 4321 et seq.), as amended; the Council on Environmental Quality Regulations for Implementing the Procedural Provisions of NEPA (40 CFR Parts 1500-1508); and the National Aeronautics and Space Administration's (NASA) policy and regulations (14 CFR Subpart 1216.3) to support the decision-making process concerning the Proposed Action and alternatives for NASA's Cassini space exploration mission. PURPOSE AND NEED FOR THE ACTION The Cassini mission is an international cooperative effort being planned by NASA, the European Space Agency (ESA), and the Italian Space Agency (ASI) to explore the planet Saturn and its environment. The mission would involve a 4-year tour of Saturn, its atmos- phere, moons, rings, and magnetosphere by the Cassini spacecraft, which consists of the

 Orbiter and the detachable Huygens Probe. The Huygens Probe would be released from the Cassini Orbiter to descend by parachute through the atmosphere of Saturn's largest moon, Titan. During the descent, instruments on the Probe would directly sample the atmosphere and determine its composition. The Probe would also gather data on Titan's landscape. The Cassini spacecraft would carry three radioisotope thermoelectric generators (RTGS) that use the heat from the decay of plutonium (Pu-238) dioxide fuel to generate electric power for the spacecraft and its instruments. The spacecraft would use radioisotope heater units (RHUS) (157 are planned), also containing plutonium dioxide, to generate heat for controlling the thermal environment onboard the spacecraft and several of its instruments. The U.S. Department of Energy (DOE) would supply the RTGS and RHUS to NASA. NASA would provide the ground communications network and two scientific instru- ments for the Huygens Probe. ESA would provide the Huygens Probe, and ASI would pro- vide major elements of the Cassini Orbiter's communications equipment and elements of several science instruments. The Cassini mission is part of NASA's program for exploration of the solar system. The goal of the program is to understand the birth and evolution of the solar system. Initially, this program concentrated on flyby or reconnaissance-type missions to the outer solar system. With the launch of the Galileo spacecraft in 1989, the program began its transition to exploration-type missions to the outer planets using orbiters and atmos- pheric probes. The Cassini spacecraft would make remote and close-up measurements of Saturn, its atmosphere, moons, rings, and magnetosphere. This information could also provide significant insights into the formation of the solar system and the conditions that led to life on Earth. [vi] ALTERNATIVES EVALUATED The Proposed Action addressed by this FEIS consists of preparing for and implement- ing the Cassini mission to Saturn to conduct a 4-year scientific exploration of the planet, its atmosphere, moons, rings, and magnetosphere. NASA proposes to launch the spacecraft from Cape Canaveral Air Station (CCAS) (formerly Cape Canaveral Air Force Station [CCAFS]) in October 1997 using a Titan IV (Solid Rocket Motor Upgrade [SRMU]) and a Centaur upper stage (i.e., Titan IV (SRMU)/Centaur) to place the Cassini spacecraft into a 6.7-year Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) trajectory to Saturn. The SRMU is the most recent upgrade of the solid rocket motor [SRM] used on the Titan IV. If the October 1997 launch opportunity were missed, a secondary launch opportunity exists in December 1997 using an 8.8-year Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory and a backup launch opportunity exists in March 1999 using a 9.8-year VEEGA trajectory. In the event that the Titan IV (SRMU)/Centaur were not available, a Titan IV (SRM)/Centaur would be used. The launch opportunities would remain the same. The alternatives to the Proposed Action evaluated in detail are a 1999 mission alter- native, a 2001 mission alternative, and the No-Action alternative (i.e., the cancellation of the mission). The 1999 mission alternative would entail dual Shuttle launches from the Kennedy Space Center (KSC), separated by 21 to 51 days, to deliver the Cassini spacecraft and the upper stages) into low Earth orbit. An on-orbit mating of the upper stage(s) and the spacecraft would be performed by astronauts followed by insertion of the spacecraft

EXPLORING THE UNKNOWN 477 in March 1999 into its 9.8-year VEEGA interplanetary trajectory to Saturn. A backup launch opportunity, a 9.4-year VEEGA, occurs in August 2000. The 2001 mission alterna- tive would use the Titan IV (SRMU)/Centaur to launch the Cassini spacecraft into a 10.3- year Venus-Venus-Venus-Gravity-Assist (VVVGA) trajectory to Saturn. The spacecraft would require 20 percent additional propellant, as well as completing development of and flight testing a high performance rhenium engine for spacecraft propulsion to accom- modate the amount of maneuvering associated with the VVVGA trajectory. An 11.4-year VEEGA backup launch opportunity occurs in May 2002. The No-Action alternative would cancel the mission. In developing the alternatives (i.e., the Proposed Action and the 1999 and 2001 mis- sions), the available options for the following key components of the mission design were evaluated: launch vehicles, interplanetary trajectories, and power sources for spacecraft electrical needs. Several criteria were used to evaluate the options: technological feasibility and avail- ability of the option for implementing the mission at the earliest opportunity, impact of the option on the ability of the spacecraft to achieve the mission science objectives, and potential of the option for reducing or eliminating environmental impacts that could be associated with the mission. The evaluation provided the following results: (1) the Titan IV (SRMU)/Centaur is the most capable U.S. launch vehicle available to implement the mission; (2) the Cassini mission to Saturn requires planetary gravity-assist trajectories; and (3) the spacecraft requires the use of RTGs to satisfy the mission electrical power needs. [vii] The overall result of the options evaluated indicates that implementation of the Proposed Action, with its three launch opportunities (i.e., primary in October 1997, sec- ondary in December 1997, or backup in March 1999), provides the greatest opportunity to achieve the mission science objectives. The 1999 mission alternative and the 2001 mis- sion alternative also are technically feasible and provide opportunities to achieve most of the science objectives planned for the mission but with less science return (i.e., data). ENVIRONMENTAL IMPACTS The only expected environmental impacts of the Proposed Action, as well as the 1999 and 2001 mission alternatives, would be associated with the normal launch of the Cassini spacecraft on the Titan IV (SRMU or SRM)/Centaur or the Shuttle. These impacts have been addressed in previous NEPA documents prepared by the U.S. Air Force (USAF) for its Titan IV launch operations at the CCAS (USAF 1986, USAF 1988a, USAF 1988b) and for the Titan IV using the SRMU (USAF 1990) and prepared by NASA for the Shuttle launches (NASA 1978, NASA 1979, NASA 1988b, NASA 1989b, NASA 1990). The evalua- tion of these alternatives also used other NEPA-related documentation, including the EIS for the Kennedy Space Center (KSC) (NASA 1979) and the KSC Environmental Resources Document (NASA 1994). For the Proposed Action, the environmental impacts of a normal launch of the Cassini spacecraft on a Titan IV (SRMU or SRM)/Centaur would result from exhaust emissions (i.e., the exhaust cloud) from the two solid rocket motors (principally aluminum oxide par- ticulates [A1203], hydrogen chloride [HC1], and carbon monoxide (CO]), which would have a short-term impact on air quality in the vicinity of the launch site; noise from the

 SRMUS or SRMs, which would not adversely impact the nearest unprotected person for the general public); deposition of acidic SRMU or SRM exhaust products, largely on the launch complex itself, but which could reach nearby marsh and surface water areas where natural buffering would substantially reduce any impacts; and short-term impacts on stratospheric ozone along the launch vehicle's flight path from the SRMU or SRM exhaust products. No substantial long-term environmental impacts would be associated with a nor- mal launch of the Cassini spacecraft for any of the launch opportunities. The radiological concern associated with the mission is the potential release of some of the approximately 32 kg (71 lb) of plutonium dioxide (consisting of around 71 percent by weight Pu-238 at launch) in the RTGS and RHUS onboard the spacecraft. In the unlike- ly event that an accident were to occur during the launch of the spacecraft (i.e., from the time of ignition of the SRMUS or SRMs, through the insertion of the spacecraft into its interplanetary trajectory), the safety features incorporated into the RTGS and RHUS, in most cases, would limit or prevent any release of the plutonium dioxide fuel. However, in the unlikely event of a launch phase accident causing a release of plutonium dioxide fuel, no health effects (i.e., excess latent cancer fatalities [above the normally observed cancer fatalities]) would be expected to occur if members of the population were exposed to the released radioactive fuel. For launch Phases 1 through 6 on the Titan IV (SRMU)/Centaur, four accident sce- narios were identified as representative of the categories of failures that could release [viii] plutonium dioxide fuel to the environment. In addition, two postulated very low probability (i.e., much lower than the probabilities for Phases 1 through 6) accident sce- narios that could occur during the interplanetary portions of the VVEJGA and VEEGA tra- jectories were identified as the short-term and long-term inadvertent reentry scenarios. The short-term scenario would involve the inadvertent reentry of the spacecraft into the Earth's atmosphere during a planned Earth swingby, and the long-term scenario would involve a spacecraft failure that leaves the spacecraft drifting in an Earth-crossing orbit and potentially reentering the Earth's atmosphere a decade to millennia later. Preliminary estimates for a Titan IV (SRM)/Centaur launch indicate that the radiological conse- quences and the risk would be similar to those for the Titan IV (SRMU)/Centaur. Depending on the accident scenario, the CCAS/KSC regional area, limited portions of the African continent under the vehicle flight path, or indeterminate locations within the global area could be impacted by plutonium dioxide fuel releases. The CCAS/KSC regional area could be impacted if a Phase 1 accident were to result in a release. Areas out- side the region (i.e., portions of the African continent; areas elsewhere around the world) could be impacted if an accident resulting in a release were to occur in Phase 5 or 6. Considering potential accidents that could result in a release across all launch phases, no excess cancer fatalities would be expected in the exposed population. No releases of plu- tonium from the RTGs to the environment are postulated if any of the representative acci- dent scenarios occurred in Phases 2, 3, or 4. During the interplanetary portions of the mission, postulated short- and long-term inadvertent reentry accident scenarios could result in releases of plutonium dioxide to the environment. However, NASA is designing the mission to avoid the potential for such acci- dents. The mission's design ensures that the expected probability of an inadvertent reen- try would be less than one in a million. If such an accident were to occur, plutonium dioxide could be released in the upper atmosphere and/or scattered in indeterminate locations on the Earth's surface. Within the exposed population of 5 billion people, approximately 1 billion people (i.e., 20 percent or 1/5 of the population) would be expected to die of cancer due to other causes. The estimated fatalities that could result from an inadvertent reentry with release would represent an additional 0.0005 percent above the normally observed 1 billion cancer fatalities. The principal method used in this document for characterizing the radiological impacts of each alternative evaluated is health effects risk. Health effects are expressed as the number of excess latent cancer fatalities (above the normally observed cancer fatali- ties) caused by exposure to the plutonium dioxide fuel. As used in this FEIS, health effects mission risk is the probability of an accident with a plutonium dioxide fuel release (i.e., the probability of an initiating accident times the probability of that accident causing a release of plutonium dioxide, since not all accidents would result in a plutonium dioxide release) multiplied by the consequences of that accident (i.e., the health effects that could be caused by the exposure of individuals to the plutonium dioxide), summed over all pos- tulated accidents. Estimates of health effects mission risk, as discussed in this FEIS, repre- sent the expectation latent cancer fatalities. The expectation health effects mission risk over all mission phases (i.e., the total or overall health effects mission risk) does not include contributions to risk from the long-term reentry scenario. [ix] For the Proposed Action, the health effects mission risk considering all launch phas- es for the primary launch opportunity would be 8.4 x 107. The health effects mission risk from the short-term inadvertent reentry accident during the Earth swingby portion of the primary launch opportunity's VVEJGA trajectory would be 1.7 x 10^3 and for the secondary and backup opportunities' VEEGA trajectories would be 1.8 x 103. The total health effects mission risk (considering all launch phases and the Earth-Gravity-Assist trajectories) from the primary launch opportunity would be 1.7 x 103 and from the backup launch oppor- tunity would be 1.8 x 103. The health effects mission risks from the Cassini mission would be small and less than the total health risks faced by the public from construction and/or operation of large industrial projects. The environmental impacts of a normal launch of the 1999 mission would be associat- ed with the normal operations of the Shuttle. These Shuttle operations would result in tem- porary impacts on air and water quality near the launch site. Because this alternative would require two Shuttle launches, impacts would occur two times separated by 21 to 51 days. During the second Shuttle launch for this mission alternative, certain accidents that may occur could result in a release of a portion of the plutonium dioxide from the RTGS to the environment. The local CCAS/KSC regional area could be impacted if a Phase 1 accident resulted in a release. Limited portions of the African land mass could be impact- ed by a Phase 2 accident, and Phases 3 and 4 accidents could impact indeterminate loca- tions within the global area. In addition, releases could occur from an accident occurring during a short-term inadvertent reentry. Potential failures and radiological consequences associated with the Earth swingby portions of the VEEGA trajectory would be expected to be identical to those analyzed for the VEEGA swingbys for the 1999 backup launch opportunity of the Proposed Action. Using estimation methods similar to that for the Proposed Action, the health effects mission risk over all the mission launch phases for the 1999 mission alternative is 2.1 x 106. The corresponding risk from a short-term inadvertent reentry during the Earth swingby portion of the VEEGA trajectories would be 1.8 x 103, and the total health effects mission risk would be 1.8 x 10.3. The environmental impacts of a normal launch of the 2001 mission alternative would be similar to those estimated for the Proposed Action. The spacecraft with a high performance rhenium propulsion engine would be launched on the Titan IV (SRMU)/Centaur. The launch accident scenarios that could result in a release of plu- tonium dioxide fuel and the associated consequences and risks would be identical to those evaluated for the Proposed Action. The overall health effects mission risk from the launch phases is 8.4 x 107. The primary launch opportunity of this 2001 mission alternative would not use the Earth for a gravity-assist (the trajectory is a VVVGA); sub- sequently, there would be no consequences and health effects mission risks associated with a short-term inadvertent reentry. Because there is no non-EGA backup launch opportunity for the 2001 mission alternative, the backup opportunity would use a VEEGA. The health effects mission risk from the backup short-term inadvertent reen- try is 1.8 x 103. The overall [x] health effects mission risk from the primary opportu- nity is 8.4 x 107 and from the backup is 1.8 x 10-3. For all launch opportunities, should the spacecraft become uncommandable any time after injection into its interplanetary trajectory and before the final planetary gravity-assist, the spacecraft could eventually reenter the Earth's atmosphere a decade to centuries later (i.e., long-term inadvertent reentry scenario). The health effects mission risk of such an event is assumed to be similar (i.e., same order of magnitude) to that estimated for the short-term inadvertent reentry for the primary launch opportunity associated with the Proposed Action. No environmental impacts would be associated with the No-Action alternative. MISSION-SPECIFIC CONSIDERATIONS The Proposed Action has the greatest potential to accomplish the mission and its sci- entific objectives. In addition, because the Proposed Action would ensure that adequate performance margins are available (e.g., spacecraft propellant available for maneuvers during the Saturn science tour), it would have the greatest likelihood to take advantage of both planned and unplanned opportunities for science return. The expected science return for the Proposed Action's December 1997 and March 1999 contingency launch opportunities would be less due to the later arrival time at Saturn. For similar reasons, the expected science return for the 1999 mission alternative using the two-Shuttle launch would be less than the return obtained from the Proposed Action. Although the 2001 mission alternative would achieve most of the planned science objectives, it would not return as much science as the Proposed Action. The larger pro- pellant tank and propellant load would reduce the overall mission performance, requir- ing the use of a specially developed rhenium spacecraft propulsion engine. Even with the use of this more efficient propulsion engine, the number of Titan flybys would be reduced from 35 to 21. Other trajectory adjustments would be necessary to conserve propellant. In addition to reducing the opportunity for obtaining the planned science return, the abili- ty of the spacecraft to take advantage of unplanned discoveries would be limited. Because

EXPLORING THE UNKNOWN 481 this alternative requires a longer flight time than the Proposed Action, and the launch would be delayed relative to the primary launch opportunity, the international partner- ships formed to develop the Cassini spacecraft, Huygens Probe, and other space-related projects could be disrupted. Because the No-Action alternative would cancel the mission, the science return would be lost, and the ability of the United States to enter into future international agreements for cooperative space activities could be impaired. [cover page] Document II-42 FINAL SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT FOR THE CASSINI MISSION Office of Space Science National Aeronautics and Space Administration Washington, DC 20546 June 1997 [iii] EXECUTIVE SUMMARY This Supplemental Environmental Impact Statement (SEIS) has been prepared in accordance with the National Environmental Policy Act of 1969 (NEPA), as amended (42 U.S.C. 4321 et. seq.); the Council on Environmental Quality Regulations for Implementing the Procedural Provisions of NEPA (40 CFR Parts 1500-1508); and the National Aeronautics and Space Administration's (NASA's) policy and procedures (14 CFR Subpart 1216.3) to support the decision-making process concerning the Proposed Action and alternatives for NASA's Cassini space exploration mission. NASA completed development of the Cassini mission Environmental Impact Statement (hereafter denoted 1995 Cassini EIS) with distribution of the Final EIS to the public and other interested parties in July 1995. The Record of Decision (ROD) was ren- dered in October 1995. The 1995 Cassini EIS contained NASA's evaluation of the poten- tial impacts of completing preparations for and implementing the Cassini mission, with particular emphasis on accidents that could potentially occur during launch and cruise phases of the mission, and which could impact human health and the environment. While the 1995 Cassini EIS analyses used the best information available at that time, the 1995 Cassini EIS noted that NASA and the U.S. Department of Energy (DOE) were continuing to analyze and evaluate additional accident scenarios specific to the Cassini spacecraft and its launch vehicle and trajectory. In both the 1995 Cassini EIS and the ROD, NASA made the commitment that, should significant differences arise between the results of the ongo- ing analyses and the 1995 Cassini EIS, NASA would evaluate the information and make a determination regarding the need for additional NEPA documentation, including sup- plementing the 1995 Cassini EIS. Updates of the safety analyses in support of the 1995 Cassini EIS were recently made available to NASA. NASA has evaluated those analyses accordingly, and has determined that the purposes of NEPA are furthered by preparation of this SEIS. PURPOSE AND NEED FOR THE ACTION The Cassini mission is an international cooperative effort of NASA, the European Space Agency (ESA), and the Italian Space Agency (ASI), to explore the planet Saturn and its envi- ronment. Saturn is the second-largest and second-most massive planet in the solar system, and has the largest, most visible, dynamic ring structure of all the planets. The mission is an important part of NASA's program for exploration of the solar system, the goal of which is to understand the system's birth and evolution. The Cassini mission involves a four-year sci- entific exploration of Saturn, its atmosphere, moons, rings and magnetosphere. The Cassini spacecraft consists of the Cassini Orbiter and the detachable Huygens Probe. The Cassini mission represents an important step in the exploratory phase of plane- tary science, with the detailed data that would be obtained from the mission providing an important basis for continuing Earth-based studies of the planets. There are five major [iv] areas of investigation planned for the Cassini Mission. An overview of each area of investigation follows: • The previous Pioneer and Voyager swingby missions to Saturn obtained only short- duration, remote-sensing measurements of the Saturnian atmosphere. These mea- surements have been sufficient to generally determine the basic composition, energy balance, temperature profile, and wind speeds in the planet's upper atmosphere. Cassini would further investigate cloud properties and atmospheric composition, wind patterns, and temperatures, as well as Saturn's internal structure, rotation, ionos- phere, and origin and evolution. The missions would involve orbits near the equator and the poles of Saturn so that the entire planet could be studied. Titan is shrouded by dense clouds; therefore, little is known about its surface. Data collected by the instruments onboard the Cassini orbiter and the Huygens Probe would provide a better understanding of the abundance of elements and compounds in Titan's atmosphere, the distribution of trace gases and aerosols, winds and tem- perature, and surface state and composition. In particular, the spacecraft's radar would penetrate Titan's dense atmosphere and reveal the moon's surface character- istics. The Huygens Probe, carrying a robotic laboratory, would perform chemical analyses of Titan's atmosphere and clouds. As the Probe descends, the onboard instruments would measure the temperature, pressure, density, and energy balance through the atmosphere to the moon's surface. The surface properties would be mea- sured remotely, and a camera would photograph the Titan panorama and relay the images to Earth via the Cassini Orbiter.

EXPLORING THE UNKNOWN 483 • Saturn's other satellites (i.e., moons) are ice-covered bodies. Cassini would investigate their physical characteristics, the composition and distribution of materials on their surfaces, their internal structure, and how they interact with Saturn's magnetosphere. Of particular interest is the half-dark and half-light moon, Iapetus. The light side of the moon is believed to be composed of ice and the dark side possibly of some organ- ic material. The data obtained by Cassini would assist in determining the geological histories of the satellites and the evolution of their surface characteristics. The Voyager swingbys in 1980 and 1981 proved Saturn's ring system to be much more complex than previously realized, with intricate dynamic interactions in most parts of the system. The short-term Voyager studies showed a wide range of unexplained phe- nomena in the rings, including various wave patterns, small and large gaps, clumping of material and small, so-called “moonlets” embedded in the rings. Long-term, close- up observations of the rings by Cassini could help resolve whether the rings are mate- rial left over from Saturn's original formation, or whether they are remnants of one or more moons shattered by comet or meteor strikes. Applied to larger-scale disk- shaped systems, the detailed studies of Saturn's rings proposed for Cassini would pro- vide important contributions to theories of the origin and evolution of the dust and gas from which the planets first formed. [v] The tilt of Saturn's ring plane changes as the planet orbits the Sun and the chang- ing angle of sunlight illuminating the rings dramatically alters their visibility. Cassini's arrival at Saturn is timed for optimum viewing of the rings, during a period when they will be well illuminated by sunlight. Upon Cassini's arrival at Saturn in 2004 when launched in October 1997, the tilt of the ring plane and resulting illumination angle would allow Cassini's instruments an unsurpassed view of the ring disk. Cassini would allow detailed studies of ring structure and composition, dynamic processes, dust and micrometeoroid environments, and interactions among the ring systems, magnetosphere, and satellites. Saturn's magnetosphere is the region of space under the dominant influence of the planet's magnetic field. Cassini would carry instruments to study the configuration and dynamics of the magnetosphere; the nature, source, and fate of its trapped par- ticles; and its interactions with the solar wind and Saturn's satellites and rings. A par- ticular phenomenon of interest is the Saturn Kilometric Radiation—a poorly understood, very low frequency, electromagnetic radiation—which scientists believe is emitted by the auroral regions in Saturn's high latitudes. Implementation of the proposed action would also ensure that the spacecraft would complete its orbital tour before 2010, when Saturn's rings would present themselves near- ly edge-on to the Earth and Sun, severely limiting the ability for detailed observations. The Cassini spacecraft incorporates three (3) Radioisotope Thermoelectric Generators (RTGS) to provide onboard electric power for spacecraft operation and sci- entific instruments. The RTGs generate electric power by utilizing the heat from decay of radioactive material. The material is an isotopic mixture of plutonium in the form of diox- ide, along with small amounts of long-lived actinides and other impurities. About 71 per- cent of the oxide mixture (by weight) is plutonium-238 (Pu-238). The three RTGS onboard the Cassini spacecraft contain a total of 32.7 kg (about 72 lb) of PuO_2, amount- ing to 1.49x1016 Bq (402,000 Ci). In addition, 129 Radioisotope Heater Units (RHUs) will be employed to regulate the temperature inside the spacecraft and for several instru- ments. Each RHU contains about 2.7 gm (0.006 lb) of mostly plutonium-238 dioxide, amounting to a collective total of about 0.35 kg (0.77 lb), or about 1.48x1014 Bq (4,000 Ci) of radioactive material in the 129 RHUS. The 1995 Cassini EIS was made available to Federal, state and local agencies, the pub- lic and other interested parties on July 21, 1995. In addition to the No-Action Alternative, the 1995 Cassini EIS addressed three alternatives for completing preparations for and operating the Cassini mission to Saturn and its moons. On October 20, 1995, utilizing the impact analyses in the EIS, along with other important considerations such as [vi] pro- grammatic, economic, and international relations, the ROD selecting the Proposed Action was rendered. ALTERNATIVES EVALUATED The Proposed Action and preferred alternative consists of completing preparations for and operating the Cassini mission to Saturn and its moons, with a launch of the Cassini spacecraft onboard a Titan IV (SRMU)/Centaur. The launch would take place at Cape Canaveral Air Station (CCAS) during the primary launch opportunity of October 6 through November 15, 1997. A secondary launch opportunity occurs from late November 1997 through early January 1998, with a backup opportunity from mid-March to early April 1999, both using the Titan IV (SRMU)/Centaur. The primary launch opportunity would employ a Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) trajectory to Saturn; the secondary and backup opportunities would both employ a Venus-Earth-Earth-Gravity- Assist (VEEGA) trajectory. The Proposed Action would allow the Cassini spacecraft to gather the full science return desired to accomplish mission objectives. Along with the No-Action Alternative, the 1995 Cassini EIS evaluated two other mis- sion alternatives. The March 1999 Alternative would have used two Shuttle flights launched from Kennedy Space Center (KSC), with on-orbit integration of the spacecraft and upper stage, followed by injection of the spacecraft into a VEEGA trajectory to Saturn. The March 1999 Alternative is no longer considered reasonable at this time due to the long lead-time in developing and certifying the new upper stage that would be needed to implement this mission alternative. When combined with the significant addi- tional costs associated with this alternative, the 1999 dual Shuttle alternative is no longer considered reasonable. The other mission alternative evaluated in the 1995 Cassini EIS was the 2001 Alternative, which would use a Titan IV (SRMU)/Centaur to launch the spacecraft from CCAS in March 2001 using a Venus-Venus-Venus-Gravity-Assist (VVVGA) trajectory. A backup opportunity in May 2002 would use a VEEGA trajectory. The 2001 Alternative would require completing the development and testing of a new high-performance rhe- nium engine for the spacecraft, as well as adding about 20 percent more propellant to the

EXPLORING THE UNKNOWN 485 spacecraft. Science returns from this alternative would meet the minimum acceptable level for the mission. RADIOLOGICAL IMPACTS OF ACCIDENTS Evaluation of the recently available safety analyses has indicated that the only parts of the previous Cassini EIS potentially affected are the analyses of the radiological conse- quences of accidents involving a potential release of plutonium dioxide (source term) from the RTGs and/or the RHUs onboard the spacecraft. The environmental impacts of completing preparations for the mission are unaffected by the updated analyses, and [vii] remain as presented in the 1995 Cassini EIS. In addition, the analyses of the environ- mental impacts of both an incident-free launch and incident-free interplanetary gravity- assist trajectory are also unaffected and remain as presented in the 1995 Cassini EIS. The EIS's and recently available analyses overall assessments of the Cassini mission's risk are similar. The updated assessment of individual mission segment accidents has iden- tified higher risks for launch segment accidents and lower risks for the Earth gravity assist (EGA) swingby segment. Both the EIS and the updated analyses indicate that only a frac- tion of conceivable launch accidents are calculated to result in releases of PuO2. The ongoing safety analysis process is similar to the process used for the earlier Galileo and Ulysses missions and has resulted in incremental improvements in the mod- eling and analysis techniques. The potential source terms are determined by using simu- lations to evaluate the response of the RTGS, RTG components, and RHUs to the defined accident environments. The ongoing analyses utilize probabilistic risk assessment tech- niques with computer simulation and modeling of RTG responses to accident environ- ments, and are based upon safety test and analysis studies performed by and on behalf of DOE. The safety test and analysis studies have been performed over the past 12 years on General Purpose Heat Source (GPHS) RTGS and materials, and RHUS. These tests pro- vide a database of the performance response of the RTGS and RHUs to simulated accident conditions such as high-velocity impacts on hard surfaces, impacts from high-velocity frag- ments, and exposure to thermal and mechanical stresses such as would be encountered in a reentry from Earth orbit or exposure to burning solid rocket motor propellant. It must be emphasized that for a release of plutonium dioxide (PuO2) to occur, the initiating accident must be followed by other events to create an accident environment that threat- ens the integrity of the RTGS and RHUS. Since the issuance of the 1995 Cassini EIS, the refinements in the evaluation of accidents and estimation of their potential consequences have resulted in revised estimates. Comparison between the 1995 Cassini EIS results and the updated results are presented in this SEIS. The 1995 Cassini EIS reported point estimates of the “expectation” and “maximum” cases. The expectation case utilized source terms for each accident scenario that were probability-weight- ed, and was based upon a range of release conditions considered in the analysis. The maxi- mum case utilized source terms that corresponded to either the upper limit deemed credible for the scenario, based on consideration of supporting analyses and safety test data, or to a total probability greater than or equal to a probability cutoff of 1x107 (1 in 10 million). The updat- ed analyses used probabilistic risk assessment techniques similar to those used for the Galileo and Ulysses missions to generate updated estimates of consequences and risk.

 The 1995 Cassini EIS utilized the concept of risk as one of the key measures in the acci- dent analyses. Risk, for the purpose of the 1995 Cassini EIS and for this supplement, is defined as the total probability of an event occurring (i.e., a release from an RTG or RHU), multiplied by the mean consequence of the event (i.e., health effects described as latent [viii] cancer fatal- ities over a 50-year period within the population potentially exposed by an accident). With respect to the Cassini accident analyses, the total probability of a release occurring is deter- mined by multiplying the probability of the initiating accident that could threaten the RTGS and RHUS, times the conditional probability that the accident will result in a release. Risk esti- mates for the Cassini mission (expressed as health effects) have been developed for each mis- sion phase/accident scenario and for the average exposed individual. The updated analyses report the best estimate of consequences and risks. While the overall probability of an accident that could threaten the RTGs or RHUs during the Cassini mission is 2.8x10^2, or 1 in 36, the probability of an accident predicted to release PuO2 is 2.8x10^3, or less than 1 in 357. Such an accident could result in 0.089 mean health effects. This results in an overall mission risk of 2.5x104, or 0.00025, health effects worldwide. This risk level is lower than the overall risk reported in the 1995 Cassini EIS (expected value of 1.7x10^3, or 0.0017, health effects). The total mission risk is distributed over four major mission segments—i.e., pre-launch (Phase 0), early launch (Phases 1 and 2), late launch (Phases 3-8) and Earth Gravity Assist (EGA). The pre-launch segment runs from 48 hours (T-48 hrs) prior to launch to T-0 sec- onds (s). The early launch segment starts with ignition of the SRMUs at T-0 s and extends through T+143 s when the SRMUs are jettisoned. The time period from T+143 s to T+206 s is not considered because there are no accidents that could result in a release of PuO2 during this time period of the mission. The late launch segment starts at T+206 s and extends to the point where the spacecraft has escaped from Earth orbit. The EGA segment encompasses the period from Earth escape to completion of the Earth swingby. Pre-launch accidents were not covered in the 1995 Cassini EIS because, at that time, none were postulated that could result in a release of PuO2. However, information recent- ly made available from the updated mission safety analyses indicates the total probability of a pre-launch accident that results in a release of PuO2 is 5.2x105, or about 1 in 19,200, and could result in 0.11 mean health effects and could contaminate 1.5 km2 (0.58 mi^2) of land above 7.4x10^3 Bq/m^2 (0.2 µCi/m^2) (the Environmental Protection Agency's [EPA's] guideline level for considering the need for further action). The total probability of an early launch accident that results in a release of plutonium is 6.7x104, or about 1 in 1,490, and could result in 0.082 mean health effects and could contaminate 1.6 km^2 (0.62 mi^2) of land above the EPA guideline level. In comparison to the 1995 Cassini EIS, this segment's mean mission risk is 0.000055 health effects, which exceeds the 1995 Cassini EIS estimate of 0.00000046. The total probability of a late launch accident that results in a release of plutonium is 2.1x103, or 1 in 476, and could result in 0.044 mean health effects and could contaminate 0.057 km^2 (0.02 mi^2) of land above the EPA guideline level. In comparison to the 1995 Cassini EIS, this segment's mean mission risk is 0.000092 health effects, which exceeds the 1995 Cassini EIS estimate of 0.00000037. [ix] The total probability of an EGA accident that results in a release of plutonium is 8.0x107, or less than 1 in 1 million, and could result in 120 mean health effects and could contaminate 15 km^2 (5.8 mi^2) of land above the EPA guideline level. In comparison to the

EXPLORING THE UNKNOWN 487 1995 Cassini EIS, this segment's mean mission risk is 0.000098 health effects, which is less than the 1995 Cassini EIS estimate of 0.0017. In addition to these new best estimate analyses, DOE has conducted a study of the uncertainty in the underlying test data and models used to estimate accident risks and consequences. This information is presented in Chapter 4 of this SEIS. Document II-43 Document title: "Statement from Daniel S. Goldin, NASA Administrator," NASA Press Release 96-159, August 6, 1996. Source: Office of Public Affairs, NASA Headquarters, Washington, D.C. Document II-44 Document title: "Meteorite Yields Evidence of Primitive Life on Early Mars," NASA Press Release 96-160, August 7, 1996. Source: Office of Public Affairs, NASA Headquarters, Washington, D.C. Document II-45 Document title: "President Clinton Remarks," August 7, 1996. Source: Office of the Press Secretary, The White House, Washington, D.C. Document II-46 Document title: Mars Expeditions Strategy Group, "The Search for Evidence of Life on Mars," September 26, 1996. Source: Office of Space Science, NASA, Washington, D.C. Mars captivated the attention of NASA and the public worldwide in 1996. That summer, a NASA-fund- ed research team announced in the journal Science that it had identified evidence of organic molecules in a Martian meteorite found in Antarctica, which suggested that primitive life may have existed on early Mars. As these documents illustrate, the discovery stimulated enthusiasm at NASA and across the nation for Mars exploration. Prior to the meteorite study, NASA had initiated a program of Mars exploration in which the agency planned to send two spacecraft, an orbiter and a lander, to Mars about every two years over a decade's time. Determined to make the search for life its overarching goal for Mars exploration after the announcement, NASA formed a multidisciplinary group of scientists to develop strategies for search- ing for signs of life on future missions. The last document is an excerpt from the group's report.

488 NASA AND PLANETARY EXPLORATION [no pagination] Laurie Boeder Headquarters, Washington, DC (Phone: 202/358-1898) RELEASE: 96-159 Document II-43 August 6, 1996 STATEMENT FROM DANIEL S. GOLDIN, NASA ADMINISTRATOR “NASA has made a startling discovery that points to the possibility that a primitive form of microscopic life may have existed on Mars more than three billion years ago. The research is based on a sophisticated examination of an ancient Martian meteorite that landed on Earth some 13,000 years ago. The evidence is exciting, even compelling, but not conclusive. It is a discovery that demands further scientific investigation. NASA is ready to assist the process of rigorous sci- entific investigation and lively scientific debate that will follow this discovery. I want everyone to understand that we are not talking about 'little green men.' These are extremely small, single-cell structures that somewhat resemble bacteria on Earth. There is no evidence or suggestion that any higher life form ever existed on Mars. The NASA scientists and researchers who made this discovery will be available at a news conference tomorrow to discuss their findings. They will outline the step-by-step 'detective story' that explains how the meteorite arrived here from Mars, and how they set about looking for evidence of long-ago life in this ancient rock. They will also release some fascinating images documenting their research." [no pagination] Donald L. Savage Headquarters, Washington, DC (Phone: 202/358-1727) James Hartsfield Johnson Space Center, Houston, TX (Phone: 713/483-5111) David Salisbury Stanford University, Palo Alto, CA (Phone: 415/723-2558) Document II-44 August 7, 1996

EXPLORING THE UNKNOWN 489 RELEASE: 96-160 METEORITE YIELDS EVIDENCE OF PRIMITIVE LIFE ON EARLY MARS A NASA research team of scientists at the Johnson Space Center (JSC), Houston, TX, and at Stanford University, Palo Alto, CA, has found evidence that strongly suggests prim- itive life may have existed on Mars more than 3.6 billion years ago. The NASA-funded team found the first organic molecules thought to be of Martian origin; several mineral features characteristic of biological activity; and possible micro- scopic fossils of primitive, bacteria-like organisms inside of an ancient Martian rock that fell to Earth as a meteorite. This array of indirect evidence of past life will be reported in the August 16 issue of the journal Science, presenting the investigation to the scientific community at large for further study. The two-year investigation was co-led by JSC planetary scientists Dr. David McKay, Dr. Everett Gibson and Kathie Thomas-Keprta of Lockheed-Martin, with the major collabora- tion of a Stanford team headed by Professor of Chemistry Dr. Richard Zare, as well as six other NASA and university research partners. "There is not any one finding that leads us to believe that this is evidence of past life on Mars. Rather, it is a combination of many things that we have found," McKay said. "They include Stanford's detection of an apparently unique pattern of organic molecules, carbon compounds that are the basis of life. We also found several unusual mineral phas- es that are known products of primitive microscopic organisms on Earth. Structures that could be microsopic [sic] fossils seem to support all of this. The relationship of all of these things in terms of location-within a few hundred thousandths of an inch of one anoth- er■is the most compelling evidence." "It is very difficult to prove life existed 3.6 billion years ago on Earth, let alone on Mars," Zare said. "The existing standard of proof, which we think we have met, includes having an accurately dated sample that contains native microfossils, mineralogical fea- tures characteristic of life, and evidence of complex organic chemistry." "For two years, we have applied state-of-the-art technology to perform these analyses, and we believe we have found quite reasonable evidence of past life on Mars," Gibson added. "We don't claim that we have conclusively proven it. We are putting this evidence out to the scientific community for other investigators to verify, enhance, attack—disprove if they can■as part of the scientific process. Then, within a year or two, we hope to resolve the question one way or the other." "What we have found to be the most reasonable interpretation is of such radical nature that it will only be accepted or rejected after other groups either confirm our find- ings or overturn them," McKay added. The igneous rock in the 4.2-pound, potato-sized meteorite has been age-dated to about 4.5 billion years, the period when the planet Mars formed. The rock is believed to have originated underneath the Martian surface and to have been extensively fractured by impacts as meteorites bombarded the planets in the early inner solar system. Between 3.6 billion and 4 billion years ago, a time when it is generally thought that the planet was warmer and wetter, water is believed to have penetrated fractures in the subsurface rock, possibly forming an underground water system.

 Since the water was saturated with carbon dioxide from the Martian atmosphere, car- bonate minerals were deposited in the fractures. The team's findings indicate living organisms also may have assisted in the formation of the carbonate, and some remains of the microscopic organisms may have become fossilized, in a fashion similar to the forma- tion of fossils in limestone on Earth. Then, 16 million years ago, a huge comet or asteroid struck Mars, ejecting a piece of the rock from its subsurface location with enough force to escape the planet. For millions of years, the chunk of rock floated through space. It encountered Earth's atmosphere 13,000 years ago and fell in Antarctica as a meteorite. It is in the tiny globs of carbonate that the researchers found a number of features that can be interpreted as suggesting past life. Stanford researchers found easily detectable amounts of organic molecules called polycyclic aromatic hydrocarbons (PAHs) concentrated in the vicinity of the carbonate. Researchers at JSC found mineral com- pounds commonly associated with microscopic organisms and the possible microscopic fossil structures. The largest of the possible fossils are less than 1/100 the diameter of a human hair, and most are about 1/1000 the diameter of a human hair—small enough that it would take about a thousand laid end-to-end to span the dot at the end of this sentence. Some are egg-shaped while others are tubular. In appearance and size, the structures are strik- ingly-similar to microscopic fossils of the tiniest bacteria found on Earth. The meteorite, called ALH84001, was found in 1984 in Allan Hills ice field, Antarctica, by an annual expedition of the National Science Foundation's Antarctic Meteorite Program. It was preserved for study in JSC's Meteorite Processing Laboratory and its possible Martian origin was not recognized until 1993. It is one of only 12 mete- orites identified so far that match the unique Martian chemistry measured by the Viking spacecraft that landed on Mars in 1976. ALH84001 is by far the oldest of the 12 Martian meteorites, more than three times as old as any other. Many of the team's findings were made possible only because of very recent techno- logical advances in high-resolution scanning electron microscopy and laser mass spec- trometry. Only a few years ago, many of the features that they report were undetectable. Although past studies of this meteorite and others of Martian origin failed to detect evi- dence of past life, they were generally performed using lower levels of magnification, with- out the benefit of the technology used in this research. The recent discovery of extremely small bacteria on Earth, called nanobacteria, prompted the team to perform this work at a much finer scale than past efforts. The nine authors of the Science report include McKay, Gibson and Thomas-Keprta of JSC; Christopher Romanek, formerly a National Research Council post-doctoral fellow at JSC who is now a staff scientist at the Savannah River Ecology Laboratory at the University of Georgia; Hojatollah Vali, a National Research Council post-doctoral fellow at JSC and a staff scientist at McGill University, Montreal, Quebec, Canada; and Zare, graduate stu- dents Simon J. Clemett and Claude R. Maechling and post-doctoral student Xavier Chillier of the Stanford University Department of Chemistry. The team of researchers includes a wide variety of expertise, including microbiology, mineralogy, analytical techniques, geochemistry and organic chemistry, and the analysis crossed all of these disciplines. Further details on the findings presented in the Science arti- cle include:

EXPLORING THE UNKNOWN 491 * Researchers at Stanford University used a dual laser mass spectrometer-the most sensitive instrument of its type in the world—to look for the presence of the common fam- ily of organic molecules called PAHs. When microorganisms die, the complex organic molecules that they contain frequently degrade into PAHs. PAHs are often associated with ancient sedimentary rocks, coals and petroleum on Earth and can be common air pollu- tants. Not only did the scientists find PAHs in easily detectable amounts in ALH84001, but they found that these molecules were concentrated in the vicinity of the carbonate glob- ules. This finding appears consistent with the proposition that they are a result of the fos- silization process. In addition, the unique composition of the meteorite's PAHs is consistent with what the scientists expect from the fossilization of very primitive microor- ganisms. On Earth, PAHs virtually always occur in thousands of forms, but, in the mete- orite, they are dominated by only about a half-dozen different compounds. The simplicity of this mixture, combined with the lack of lightweight PAHs like napthalene, also differs substantially from that of PAHs previously measured in non-Martian meteorites. * The team found unusual compounds—iron sulfides and magnetite—that can be pro- duced by anaerobic bacteria and other microscopic organisms on Earth. The compounds were found in locations directly associated with the fossil-like structures and carbonate globules in the meteorite. Extreme conditions-conditions very unlikely to have been encountered by the meteorite-would have been required to produce these compounds in close proximity to one another if life were not involved. The carbonate also con- tained tiny grains of magnetite that are almost identical to magnetic fossil remnants often left by certain bacteria found on Earth. Other minerals commonly associated with biolog- ical activity on Earth were found in the carbonate as well. * The formation of the carbonate or fossils by living organisms while the meteorite was in the Antarctic was deemed unlikely for several reasons. The carbonate was age dated using a parent-daughter isotope method and found to be 3.6 billion years old, and the organic molecules were first detected well within the ancient carbonate. In addition, the team analyzed representative samples of other meteorites from Antarctica and found no evidence of fossil-like structures, organic molecules or possible biologically produced compounds and minerals similar to those in the ALH84001 meteorite. The composition and location of PAHs organic molecules found in the meteorite also appeared to confirm that the possible evidence of life was extraterrestrial. No PAHs were found in the mete- orite's exterior crust, but the concentration of PAHs increased in the meteorite's interior to levels higher than ever found in Antarctica. Higher concentrations of PAHs would have likely been found on the exterior of the meteorite, decreasing toward the interior, if the organic molecules are the result of contamination of the meteorite on Earth. Additional information may be obtained at 1 p.m. EDT via the Internet at http://www.jsc.nasa.gov/pao/flash/

EXPLORING THE UNKNOWN 573 Prepared for National Aeronautics and Space Administration Washington 25, D. C. Prepared by. American Science and Engineering, Inc.. 11 Carleton Street Cambridge 42, Massachusetts 25 September 1963 Approved: [signature] Riccardo Giacconi Vice President Space Research and Systems Division ******** [12] [section] II. REQUIREMENTS FOR FUTURE X-RAY OBSERVATIONS The discovery of galactic X-rays, together with the various hypothesis [sic] that have been put forward to explain them raise two obvious questions which must be answered in future observations: 1. What are the precise position, distances and dimensions of the discrete sources? 2. Do all X-rays come from discrete sources or is there a general diffuse background? A great elaboration of the observational techniques will clearly be required in order to answer these questions and the new ones which will arise in the course of the develop- ment of X-ray astronomy. In common with technical developments for astronomical observations in other regions of the spectrum, those needed for X-ray astronomy will be directed toward: 1. All-sky surveys with increased angular resolution and increased sensitivity to dis- tinguish discrete sources and the diffuse background; 2. Higher resolution studies of the structure of individual sources; 3. Increased spectral resolution both for discrete and diffuse sources: 4. Study of the detailed properties of X-ray emissions such as secular changes and polarization. [13] In view of recent developments in X-ray optics and methods of detection it is now pos- sible to plan along range program of X-ray observations with the assurance that the tech- nical means exist for carrying it out. [14] III. INSTRUMENTATION The instrumentation which is utilized in most of the experiments here proposed is based on two new instruments recently developed at American Science and Engineering, Inc. a photoelectric X-ray detector and an X-ray telescope. These instruments furnish orders of magnitude greater sensitivity and finer angular resolution than the conventional instrumentation.

 1. Photoelectric X-ray Detector The photoelectric X-ray detector utilizes the alkali halides as a photoelectron emitting surface for X-rays in the region between 2 and 100 Å. (Lukirskii 1960). A prototype of the detector has been constructed and tested at American Science and Engineering, Inc. The laboratory tests have confirmed the results of Lukirskii, et al., for SrF_2 and have been so promising that this detector was chosen for the OSO-D wheel experiment presently being carried out under NASA Contract NAS 5-3569. The principal advantages of this type of detector with respect to conventional Geiger counters are: 1. The use of extremely thin windows which extends the range of observable soft X-ray wavelengths to the 20 - 100 Å region; 2. The ease of obtaining extremely large detecting areas; [15]3. The relatively low background noise; 4. The extremely long useful life of the device. The detector is described in detail in the ASE proposal ASE-334, “Experiment to Measure Extra-Solar X-Radiation from the Rotating Wheel Section of the OSO-D Satellite". 2. The X-Ray Telescope The X-ray telescope which is proposed for use in phases VI and VII of the proposed research program utilizes the principle of total external reflection of X-radiation at grazing incidence to form X-ray images in the focal place of the device. This instrument was first pro- posed by Giacconi and Rossi in 1960 (Giacconi 1960). It has been developed under NASA sponsorship (NAS 5-660) and is presently utilized on OSO-D for a pointed wheel solar X-ray experiment being carried out by ASE (NAS 5-3569). It is also being used on a pointed rock- et experiment to obtain an X-ray picture of the Sun on recoverable photographic emulsion which is being carried out as a joint ASE-GSFC program (NAS 5-3401). A description of the principle of operation is given in the NASA document X-614-63- 112, "High Resolution (5 arc sec) X-Ray Telescope for Advanced Orbiting Solar Observatory". The principle advantages of using an X-ray telescope are: 1. Large areas of collection; 2. Extremely fine angular resolution (the theoretical limit is a few seconds of arc) coupled to ease of alignment. [16]3. Orders of magnitude improved signal to noise ratio due to the focussing; 4. Ease of construction by use of traditional optical instruments manufacturing tech- niques. [17] IV. THE PROPOSED RESEARCH PROGRAM This program consists of three major steps. First, an all-sky survey is proposed from rock- ets (Phase I), OSO-D (Phase II) and a scanning X-ray satellite (Phase III) which culminates in the detection of sources 100 to 1000 times weaker than presently detected with a resolu- tion of 1 degree and with preliminary spectrum information in the 0.1 to 60 Å region. The second step consists of use of pointing systems to study in detail some of the observed sources or pre-selected potentially interesting objects. Phase N is an experi- ment to be performed by a crew member in the Gemini capsule. Phase V is a non-prime experiment to be performed from OAO. The possibility of pointing permits us to

EXPLORING THE UNKNOWN 575 devote much longer time to the detailed study of single sources than is possible in a scanning experiment. The third step is the introduction of imaging techniques in galactic and extragalactic X-ray observations. Phase VI is a prime experiment from OAO with a 10 foot telescope which will furnish a collecting area of about 38 cm^2. An improved version of this experi- ment is Phase VII, where a 30 foot telescope with an area about 400 cm^2 is proposed. The angular resolutions which now become possible are of the order of seconds of arc for detailed study of the structure of galactic and extragalactic sources. Even though of necessity the latter phases of the program become less specific, it is believed that the execution of the entire program is well within the state of the art. A pre- liminary time schedule is shown in Figure 2. [18]

576 NASA AND PLANETARY EXPLORATION Document III-9 Document title: Nancy Roman to NASA Associate Administrator for OSSA, “NASA Support of Ground-based Astronomy," March 16, 1965. Source: NASA Historical Reference Collection, History Office, NASA Headquarters, Washington, D.C. In March of 1959, NASA Administrator T. Keith Glennan and Deputy Administrator Hugh Dryden had reached an agreement with National Science Foundation (NSF) Director Alan Waterman regard- ing a division of responsibility between the two agencies for funding of astronomy research. Under the memorandum of understanding, NSF received authority over ground-based astronomical research, while NASA would fund space-based astronomical studies. Officials from both agencies soon realized the difficulty of making such a strict division work when research efforts often relied on the results of studies conducted both in space and on the ground; NASA thus adopted a policy of funding ground- based research that strongly supported its space program. In 1965, a team led by NASA Astronomy Chief Nancy Grace Roman reviewed this policy in response to a request by the White House Office of Science and Technology that NASA and other Government agencies evaluate a National Academy of Sciences commission's assessment of the needs of ground-based astronomy. Roman's group did not advocate any changes to the policy, but recommended that NASA increase funding to support ground- based astronomy. [1] [stamped "MAR 16 1965"] S/Associate Administrator for Office of Space Science and Applications SG/Chief of Astronomy Physics and Astronomy Programs NASA Support of Ground-based Astronomy The excellent review of the needs of astronomy and astronomers prepared by the National Academy of Sciences committee chaired by Dr. A. E. Whitford has stimulated a detailed re-examination of government support of astronomy. As part of this re-examina- tion, I have discussed the NASA policy on support of ground-based astronomy with the Astronomy Subcommittee of the Space Science Steering Committee and with Drs. Liddel, Brunk, Holloway, Smith, and Mr. Scott. For reference the policy which has been followed within OSSA may be summarized as follows: "General support of astronomy is the province of the National Science Foundation. NASA cooperates with this and other government agencies in an attempt to insure sup-

EXPLORING THE UNKNOWN 577 port of deserving programs and to discourage any possible attempt to stimulate competi- tion between agencies. However, it is obvious that the exploration of space must intimately involve both astronomers and astronomical research. It is difficult to conceive of any area of astronomical research which has no contact with space exploration. Moreover, in many areas of its program, NASA urgently needs additional astronomical research both to plan its programs intelligently and to interpret the results obtained. Therefore, NASA has undertaken the support of both astronomical research and astronomical facilities in those areas of astronomy which most directly affect the space program. In addition it has used the flexibility of its SRT program, its field center research, its training grants, and its facil- ities grants to support, at a lower level, an important broader a of astronomical research from which more closely mission-oriented research must arise." Both groups consulted endorsed the present policy and urged that NASA support of astronomy be enlarged somewhat within the broad guidelines of this policy. They further agreed that, on the whole, the Whitford committee report is well thought out and outlines a program which is well conceived and, at least in optical astronomy, con- servative. However, it is our recommendation that the major responsibility for the [2] implementation of this report lies more appropriately with the National Science Foundation. Within NASA, support of astronomy should remain as it is now, a program activity in OSSA. Program funds should be in-creased to cover a relatively modest increase in support of ground-based astronomy, including research, support of existing observatories, and support of new instruments. A line item in the NASA budget is nei- ther necessary nor desirable. In this context, we have reviewed NASA support of various areas of astronomy, with particular emphasis on the instruments recommended by the Whitford report. We agreed that it is probably not desirable for NASA to take an active part in the design and con- struction of either the largest feasible optical reflector or the largest feasible steerable paraboloid for radio astronomy. These general instruments fall within the traditional province of the National Science Foundation which should continue to retain responsi- bility for them. At the present time NASA has no foreseeable requirement for large opti- cal telescopes in the 150-200 inch class. Funds for the three such instruments recommended by the Whitford paper appear to be available elsewhere. In addition to the telescopes now being built at the University of Arizona and the University of Texas, we foresee the need for major NASA access to two or three additional telescopes of the 60- to 120-inch class in the next few years. We also foresee the desirability of NASA support of at least one or two optical telescopes per year in the 24- to 50-inch class. For tracking satellites and space probes, NASA requires instruments similar to those used for astronomical observations. The instruments should be made available for astro- nomical research on a non-interference basis to the maximum feasible extent as the Baker-Nunn telescopes are now used for flare star photometry and the 85-foot antenna at Rosman is being adapted to radio astronomy. Particularly in the case of the larger instal- lations, such as the 210-foot dishes of the deep space net, the possibility of radio astro- nomical use should be considered in this design stages. NASA is exploring large phased arrays for tracking purposes. The results of researches on such arrays should be made freely available to the astronomical community to direct and support research of mutual benefit to both NASA tracking requirements and radio astronomy.

578 NASA AND PLANETARY EXPLORATION At the present time we do not foresee an obvious programmatic need for NASA to support the other major radio astronomical facilities recommended in the Whitford report. Hence, the responsibility for these [3] facilities should remain with the National Science Foundation. We should undoubtedly continue to support smaller special purpose instruments of particular interest to our programs, as we have in the past supported the low frequency radio astronomy arrays at the University of Maryland and the National Bureau of Standards and the accurate millimeter radio telescope at the University of Texas. It may also be desirable for NASA to support special purpose instruments for the near, intermediate, and far infrared regions of the spectrum. Two areas of ground-based astronomy are conspicuously lacking from the Whitford rec- ommendations. These are radar astronomy and solar astronomy. NASA should continue to partially support the use of existing large radars for special astronomical problems, including both instrumentation directly controlled by NASA and those radars built by other agencies. We do not, at present, foresee NASA support for the construction of new radar facilities, although further experience with radar exploration of the solar system may modify this conclusion. In solar astronomy, specialized, modest scale instruments like coronographs and cinemonochro- mators play a vital role in supporting satellite observations of the sun; two or three additional installations will be required to adequately back up the solar observatories flight program. We also estimate that NASA will want to support about five additional flare patrol photoheli- ographs and at least one intermediate-sized solar tower (telescope and spectrograph). We may wish to provide partial support of the Sacramento Peak vacuum telescope, if necessary, to guar- antee its erection. Some support of other existing facilities may also be desirable. In addition to support of telescope construction, several other areas of ground-based astronomy support merit consideration. NASA should plan to provide a major share of the continuing operational support for those instruments the construction of which we have funded as long as the research conducted is of interest to NASA. We should also increase support of other telescope operations to insure optimum productivity in those areas par- ticularly relevant to the NASA flight missions. This support should include purchase or construction of auxiliary instrumentation, as well as of specific research projects. NASA is in an unusually good position to cooperate in the development of automat- ed instrumentation for ground-based astronomy. NASA has developed many automated techniques for both unmanned observations in space and ground-based reduction of large quantities of data which [4] could be adapted to astronomy. In turn, the further development of such techniques in ground-based astronomy may contribute significantly to NASA's increasing need for automated techniques in data acquisition and reduction As long as NASA is charged with the scientific exploration of space, we shall continue to rely as astronomers both as full time participants in our program or as consultants on special problems. Therefore, we should continue our present policy of supporting astro- nomical education in the following ways: 1. Encouragement of the award of NASA training grants to pre-doctoral astronomy students. 2. Continued use of pre- and postgraduate student assistants on research projects of interest to NASA. 3. Continued support and encouragement of summer institutes for astronomy and related areas.

EXPLORING THE UNKNOWN 579 In summary, we recommend no major change in current NASA policy, but recom- mend an increase in the amount of program funds available to support astronomical research and facilities. cc: SG/Naugle, Smith SL/Brunk, Liddel SC/Holloway, Scott SS/Clark S/Newell SG [signature] John E. Naugle [stamped "16 MAR 1965"] [signature] Nancy G. Roman Document III-10 Document title: "Space Research: Directions for the Future - Report of a Study by the Space Science Board," Woods Hole, Massachusetts, 1965. Source: Space Studies Board, National Research Council, National Academy of Sciences, Washington, D.C. In 1962, the Space Science Board brought scientists together to conduct a major review of recent and future space research. One of the study's most significant outcomes came from the Working Group on Astronomy, which envisioned a large, space-based telescope as the next logical step after the Orbiting Astronomical Observatories. Three years later, when the Space Science Board convened another major review of space research, the Working Group on Optical Astronomy was tasked with assessing the util- ity of large aperture telescopes for optical astronomy. As its members were enthusiastic supporters of space astronomy, the group strongly recommended in the report of the study that NASA develop what they referred to as a Large Orbital Telescope. Soon thereafter, NASA began research on the pointing system for the facility that eventually became the Hubble Space Telescope. [147] [Chapter] II: Optical Astronomy 1. SUMMARY AND RECOMMENDATIONS The Working Group on Optical Astronomy was organized “to examine the future needs of optical astronomy for large-aperture orbiting telescopes of a generation beyond the orbiting astronomical instruments which are now being readied for launching.” The Group interpreted this charge to include the space program for optical astronomy generally, since consideration of large instruments requires study of the scientific data as well as engineering experience gained with small instruments. As applied to the Working Group's area of concern, optical astronomy in space was defined to include all astronom- ical research carried out with reflecting telescopes in space at wavelengths from 800 Å to 1 mm, excluding solar studies. In terms of the instruments used, this definition is logical, since a conventional optical telescope with near-normal-incidence reflecting optics can be used for a wide variety of observational studies in this wavelength range. At the lower wave- length limit, somewhat shorter than 912 Å, mirror reflectivities tend to be low, and stellar radiation is probably completely cut off by the interstellar hydrogen absorption. Above the upper limit of 1 mm, the atmosphere becomes transparent and larger radio telescopes on the Earth's surface are more effective. (Solar research, with different prob-lems of ther- mal control and guidance requirements, needs different types of telescopes from those used for observing stars, stellar systems, nebulae, and planets, and was therefore the sub- ject of study by a different Working Group.) The space astronomy discussions at Woods Hole in 1965 were in some ways a contin- uation of earlier discussions by the Astronomy Working Group at the Iowa Summer Study Group in 1962 ("A Review of Space Research," Publication No. 1079 of the National Academy of Sciences-National Research Council). During the three-year interval since that earlier study, great strides in space technology have been made. Large rocket boost- ers have placed tons of equipment in orbit, and the Gemini flights in the spring of [148] 1965 have shown that man can operate effectively in space, even outside the spacecraft. The progress of optical space astronomy in the study of objects other than the Sun has been impeded by the difficult pointing requirements, but the accumulating data on ultra- violet stellar spectra obtained with sounding rockets (including a recent spectrogram with 1 Å resolution), and the progress made in fabricating and testing Orbiting Astronomical Observatories, suggest that rapid progress in this field can now be expected. The Woods Hole discussions naturally reflect the confidence resulting from these developments. The present report is designed primarily to present the recommendations made by the Working Group, together with enough background material to explain the chief rea- sons underlying each specific recommendation. Many of the auxiliary points discussed by the Group are not mentioned here. To provide general background information, Section 2 presents a brief discussion of some of the most important and striking research objec- tives of astronomy in general and of optical astronomy in space in particular. Section 3 [sections 3-5 not included] discusses the short-range program in optical space astronomy, including flights planned during the next ten years, and related programs in astronomi- cal instrumentation, optical design, and ground-based research generally. Section 4 is devoted to the longer-range goal of a large space telescope. Section 5 comprises three appendixes -- the working papers of the Group. RECOMMENDATIONS The Working Group on Optical Astronomy has considered the possibilities for studying stars, star systems, nebulae, and planets by means of telescopes in space sensi- tive to electromagnetic radiation at wavelengths between 800 Å and 1 mm. For the short- range program (1965-1975), the following recommendations (all summarized here) have been made:

EXPLORING THE UNKNOWN 581 (1) The number of coarse-pointing sounding rockets available each year for optical space astronomy should be increased to twice the present level. (2) Two or more telescopes having apertures of 40 inches or larger should be includ- ed in the Apollo Extension Systems (AES) program. The Orbiting Astronomical Observatory (OAO) program should be continued until AES launchings are def- initely scheduled. (3) Development of various detectors required in space telescopes should be sup- ported by NASA. (4) Development of improved gratings would be of central importance in the space astronomy program. (5) Development of optical interferometers should be pressed, with probable initial operation on the ground. (6) Research and development concerned with problems of space [149] telescope optics, especially with the primary mirror, should be supported by NASA. (7) Support of ground-based astronomy should be increased, as such support is urgently needed for the continuing healthy growth of astronomy in general and of space astronomy in particular. With regard to the long-range program (after 1975), the Working Group has con- cluded that the focus of the national effort in optical space astronomy generally should be toward, and in the context of, a very large orbital telescope to be used with a wide variety of astronomical instrumentation. To help pursue this objective the following recommend-ation (given in full here) was adopted: (8) We conclude that a space telescope of very large diameter, with a resolution corre- sponding to an aperture of at least 120 inches, detecting radiation between 800 Å and 1 mm, and requiring the capability of man in space, is becoming technically feasible and will be uniquely important to the solution of the central astronomical problems of our era. We recommend that the Space Science Board of the National Academy of Sciences appoint an ad hoc panel to work toward this Large Orbital Telescope and to encourage studies of those critical areas where particular research and development is required in the near future to further this program. ******** [162] Infrared telescope. A telescope designed to be diffraction-limited at a wavelength somewhere between 10 and 100 microns might conceivably be made very much larger than an instrument designed for ideal optical performance at 0.5 micron. Until this field of research has been explored more fully from the ground and from space, the value of such a specialized instrument cannot be assessed. Interferometer. The beam interferometer, designed to achieve very high resolution on particular objects, would be a useful instrument in optical astronomy. Current efforts to use this technique from the ground have been discussed above, and further information is required before the need for interferometric equipment in space can be evaluated.

 After study of these various points the Working Group concluded that at present the long-range program in optical astronomy should be concentrated on a single general-pur- pose telescope, though special-purpose instruments might be included at a later date, when and if a clear demonstration of their value can be made. Following considerable discussion the Working Group adopted the following recom- mendation: Recommendation 8 We conclude that a space telescope of very large diameter, with a resolution correspond- ing to an aperture of at least 120 inches, detecting radiation between 800 Å and 1 mm, and requiring the capability of man in space, is becoming technically feasible and will be uniquely important to the solution of the central astronomical problems of our era. We recommend that the Space Science Board of the National Academy of Sciences appoint an ad hoc panel to work toward this Large Orbital Telescope and to encourage studies of those critical areas where particular research and development is required in the near future to further this pro- gram. (See p. 2-21 for considerations leading to the last part of this Recommendation.) Confidence in the technical feasibility of a diffraction-limited 120-inch space tele- scope was based on the various technical studies carried out for NASA directly or indi- rectly by various groups (Boeing, American Optical, Perkin-Elmer); the engineering problems of such a large instrument were discussed only briefly by the Group. The design goal of a 120-inch aperture was adopted in the belief that a long-range instrument should be a very significant advance over the insturements [sic] used in the Stratoscope and OAO programs, whose apertures are in the 30 to 40 inch category. The aperture could well be greater than 120 inches, if that proves technologically feasible (see page 17). [163] It was the conviction of the Group that this large instrument could provide a dra- matic central focus for the optical space astronomy program, and that it would be an appropriate major space program for the nation. It was to help emphasize the central character of this instrument in the national space effort that the name “Large Orbital Telescope" (LOT) was proposed. While the term “orbital” was used for this large-span tele- scope, the possibility of a lunar location was not strongly excluded. Clearly, adoption of the LOT program would have a significant impact on the short- range program in optical space astronomy. While the short-range program discussed in Section 3 is designed primarily to obtain significant scientific results, the data obtained and experience gained would be absolutely essential for the LOT effort. In particular, the AES effort could be an important forerunner of the manned high-resolution LOT. In gen- eral, considerable expansion of much of the short-range program might be required if the LOT were to be effectively used within the time scale outlined below. The subsequent sections discuss the possible design parameters for the Large Orbital Telescope, a time schedule that may be visualized for its construction, and some adminis- trative problems that might be associated with this enterprise. DESIGN PARAMETERS The general characteristics of a large space telescope, discussed in earlier sections of this report, apply to the LOT as well. Thus, this large telescope would be a general-purpose instrument, focusing electromagnetic radiation in the wavelength range from about 800 Å to 1 mm. The Group discussed briefly the engineering problems of this telescope and the design parameters that might be chosen in view both of these problems and of the scientific objectives. While no recommendations were adopted on most of these items, the conclusions are summarized here for reference. Aperture For reasons already outlined, the goal of designing a diffraction-limited 120-inch tele- scope was adopted by the Group. The actual diameter of the instrument would depend, of course, on the technical situation at the time the instrument was designed. One possibility discussed by the Group was that the actual diameter might substantially exceed 120 inch- es, but with the image size corresponding to a diffraction-limited 120-inch mirror. Such an increase in light-gathering power would be desirable for many researches and might be technically feasible if a corresponding decrease [164] in angular image diameter were not required. (If the Saturn V were used to place the LOT in orbit, and the primary were a sin- gle mirror, the diameter could not exceed 250 inches; without doubt, other engineering considerations would limit the diameter to a substantially smaller figure.) Role of Man It was generally agreed that the LOT should be usable for many decades, with occa- sional changes and improvements in the instrumentation provided at the focal plane. This requirement can presumably not be met unless a man is intimately involved in maintain- ing and repairing the equipment, and presumably a man will also be required for the ini- tial adjustment and operation. The design of the LOT should provide for ease in trouble shooting, for access to all parts of the telescope, and for replacement of defective mod- ules. The extent to which a man should actually operate the telescope is a matter of debate, and it is not excluded that the entire system should be completely automated. Guidance on stars will presumably be automatic, and, during this time, man should prob- ably not be coupled to the instrument. However, guidance by man might prove useful for observations of a rotating planet, for which automatic guidance would be difficult. Similarly, in a crowded star field, acquisition of the desired object by a man might be use- ful, though this could be done through use of a television camera rather than by looking through the telescope. There was agreement that the instrument should be completely controllable at will, either by equipment on the ground or by a man nearby. There was some discussion of the likelihood of failures resulting from human error. Location After reviewing the recommendations of the Report on Lunar Exploration Systems after Apollo (LESA, North American, 1965), the Group discussed the relative advantages of the following three different locations for a large space telescope: low orbit (below the Van Allen belts), at 400 km altitude or less; high orbit (above the Van Allen belts), at 30,000 km altitude or more; and on the Moon. Most of the considerations examined would appear to favor the high orbit. As compared with location on the lunar surface, the advantages of a high orbit include no gravitational flexure, no secondary micrometeorites, and lower cost. A possible major disadvantage of the high orbit is greater risk of exposure of equipment and men to high-energy radiation from solar flares, though evidence presented to the Group suggests that adequate shielding is no problem. Objects close to the Sun, however, might be more difficult to observe from a high orbit than from the lunar surface. As com- pared with a low orbit, the advantages of the high orbit are: negligible occultation of objects by the Earth [165] (in a low orbit, occultations complicate the programming and are likely to reduce the net observing time by about one half); nearly constant thermal envi- ronment, which much simplifies the maintenance of the mirror figure; reduction of exter- nal torques due to gravity gradients, magnetic fields, and air drag by at least two orders of magnitude, with resultant simplification of the guidance problem; darker sky than in low orbit, where airglow may contribute light; and virtual absence of oxygen atoms striking the telescope and oxidizing the aluminum. From a high orbit, communication with the ground might be simplified by continuous radio contact, but, as compared with a low orbit, com- munication would be complicated by the increased distance. The greater exposure to solar flare radiation may be an important disadvantage of the high orbit, especially in view of the longer time (at least 10 hours) required to return a human operator to Earth from the high orbit. A very clear disadvantage of a high orbit is that it requires a Saturn V for launching instead of a Saturn IB; since this additional cost would be required for each visit by men, this could be a conclusive argument for the low orbit. The Working Group unanimously came to the conclusion that, on technical grounds, the high orbit appears at the moment to be the optimum location for the LOT. Optical Design A conventional parabola-hyperbola or a Ritchey-Chrétien system seems indicated. The primary should have a relatively low focal ratio to minimize the over-all length of the instrument. Use of the prime or Newtonian focus would not seem to offer any particular advantages, and all of the instrumentation would presumably be at the Cassegrain focus, possibly with tiltable mirrors to direct the light toward the desired instrument or sensor. Careful baffling would be required to keep earthlight as well as sunlight out of the opti- cal path, and the secondary supports should presumably be apodized (with Couder strips). Automatic focusing would presumably be required and, probably, automatic col- limation as well. [167] ADMINISTRATIVE PROBLEMS Three different phases of the program were considered: (a) preliminary phase, (b) design and construction, and (c) post-launch operation. As entirely different adminis- trative problems would be encountered in each of these phases, they are discussed sep- arately here. Preliminary phase Such a major astronomical effort as the LOT should not be undertaken until a major- ity of the astronomical community supports the program with enthusiasm. It appears to the Working Group that progress in space research generally, and in space astronomy par- ticularly, combined with increasing awareness of the close interdependence of space astronomy and ground-based astronomy, may help in generating enthusiasm for the LOT among U.S. astronomers.

EXPLORING THE UNKNOWN 585 To help in explaining LOT plans to their colleagues, and in pressing for the program generally, the Working Group concluded in effect that the Group as a whole, or a repre- sentative fraction of it, should continue in existence, as an ad hoc panel, and requested the National Academy of [168] Sciences to endorse a proposal to this end as contained in Recommendation 8, page 3. The purpose of the panel would be: (i) To attempt to broaden the base of support, for (a) the space astronomy program in general, and for (b) an eventual launching of a large astronomical instrument in par- ticular. By discussion with their colleagues, they would hope to clarify the issues involved and to stimulate the interest of astronomers who are at present unfamiliar with the aims of the space program. (ii) To begin an orderly examination of some of the technical problems that will arise in the design of a large orbiting telescope, anticipating that more permanent arrange- ments will be made later. (iii) To implement these two aims by holding fairly frequent informal meetings, preparing discussions of specific subjects, inviting the participation of other astronomers, and generally to keep alive the idea of working toward a large orbital telescope. Design and construction phase In the initial organization of the program and during all successive stages until launch, there must be close and effective contact between NASA and its engineering contractors, on the one hand, and the astronomical community on the other. How this contact can best be maintained and integrated into the vast administrative structure required for such a large program is a question that deserves careful study. Perhaps a group of astronomers might be organized to carry out detailed design studies, with advice from engineers and optical experts; such a group might then serve in an advisory capacity during the engineering design phase that would follow. Perhaps a committee under the National Academy of Sciences, with representatives from various interested groups, might serve a useful function in this context, and might help to provide a bridge between the NASA organization for the LOT and the. sci- entific community. Further exploration of these and other possibilities is desirable. Operations phase Clearly, the LOT would be a truly national facility, and should be administered as one. The plan should be workable from the standpoint of NASA's internal administration, since the sit- uation would be complicated by the fact that flights would be involved. The Working Group visualizes that the detailed program for operating the LOT (allotment of observing time, expe- ditious recovery of data, proposals to place auxiliary instruments of newer design on board, etc.) would need to be managed in a way analogous to present ground-based national facili- ties. Responsibility for detailed scheduling must be defined, as it would depend not only on the scientific [169] program but also on such factors as the relative position of the telescope, the Earth, the Sun, the object to be observed, communications, etc. Experience with the OAO- D program, in which two-thirds of the observing time will be allotted to guest investigators (i.e., investigators other than the principal investigator, who is responsible for the experiment), may help to reveal some of the administrative problems in these areas.

586 NASA AND PLANETARY EXPLORATION Document III-11 Document title: Letter to Dr. Norman F. Ramsey, Harvard University, from James Webb, Administrator, NASA, January 14, 1966. Source: NASA Historical Reference Collection, History Office, NASA Headquarters, Washington, D.C. Document III-12 Document title: NASA Ad Hoc Science Advisory Committee, “Report to the Administrator," August 15, 1966. Source: NASA Historical Reference Collection, History Office, NASA Headquarters, Washington, D.C. In January 1966, NASA Administrator James Webb sent a letter to Norman Ramsey of Harvard University requesting that he head an ad hoc committee to recommend how NASA ought to pro- ceed on a variety of space science activities, including the ways in which NASA could involve the academic community. Among its tasks, the committee was asked to provide advice on how NASA should develop and manage a major space observatory project that the National Academy of Sciences' Space Science Board had proposed the prior summer. The Ramsey committee's response to NASA's request regarding the space observatory focused largely on the management of such a facility. In particular, the committee strongly endorsed the concept that a consortium of universities, which it called the Space Telescopes for Astronomical Research, Inc., or STAR, be established and charged by NASA to select and manage the scientific investigations that would be conducted on the space observatory. Although NASA was reluctant to give so much authori- ty to an external group so quickly, the space agency did establish an astronomy advisory group made up of non-NASA scientists, and ultimately awarded management of the Hubble Space Telescope's scientific operations to a non-NASA entity. [1] Document III-11 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WASHINGTON. D.C. 20546 January 14, 1966

EXPLORING THE UNKNOWN 587 OFFICE OF THE ADMINISTRATOR Dr. Norman F. Ramsey Harvard University Cambridge, Massachusetts Dear Dr. Ramsey: The purpose of this letter is to request you to assemble and chair an Ad Hoc Science Advisory Committee to advise NASA in the execution or [to ascertain] the major new pro- jects which are either underway or under serious consideration within the agency. These projects are the Voyager/Automated Biological Laboratory Program, the post-Apollo lunar exploration program, and the National Space Astronomy Observatories recom- mended by the Woods Hole Summer Study. As you are well aware, the objectives of those large complex programs have been devel- oped through an intensive interaction with the scientific community and, I believe, are well accepted by that community. The objectives and goals of Voyager have been reviewed by the President's Science Advisory Committee, so you are well aware of the aims of that Program. In view of the interaction which has taken place with the scientific community, you may question the need for further consultation and work on the part of people such as yourself and the others we would like to see on the advisory group. The need for such a group arises from the problems involving the scientific community due to the size, [2] complexity, and long lead time of these projects. In the past, scientists at universities and Government laboratories have been able to participate directly in the program by conceiving, designing, and building their own experimental apparatus, which was then inte- grated into a spacecraft and flown. After the flight, the scientist received the data and was able to analyze the data and publish the results in the established tradition of academic research. We in NASA think it is essential that competent scientists at academic institutions par- ticipate fully in the next generation of space projects, and we believe that we will need new policies and procedures and perhaps new organizational arrangements in order to enable them to participate. The next generation of space astronomy projects is an example of some of the problems we face. The astronomers at Woods Hole recommended that NASA develop 120-inch tele- scopes for space astronomy. We envision such an instrument as a National Astronomical Observatory in Space – an astronomical facility in space for astronomers to use, rather than the separate instruments developed by individual scientists such as we have on the Orbiting Astronomical Observatory. We estimate that it will require at least a decade to bring such a facility into being. During that period NASA will have to work closely with many of the most competent astronomers in the country. We have a nucleus of competent astronomers and engineers at the Goddard Space Flight Center; however, we expect that nucleus will have to be strengthened. It is exceedingly important that we have highly competent scientists and engineers at the Center responsible for a major astronomical facility and that we have the proper kinds of people in positions of leadership at the Center. [3] As another example, it would appear that the Automated Biological Laboratory (ABL) will have to be a “laboratory" to be used by scientists, rather than a "collection" of individual experiments designed and built at several institutions. The requirements for sterilization and the severe constraints on weight imposed by the low surface pressure on Mars dictates that the ABL must be a tightly integrated package, designed and built under the most exacting conditions in complex facilities which will be too expensive to dupli- cate. However, the most competent biologists and physicists in the country must be deeply involved in the conception, design, fabrication, and testing of ABL to assure the success of the mission. Furthermore, this must be a continuing involvement over a period of six to eight years prior to launch. Obviously, great care must be taken in the assignment of responsibility for ABL and the selection of key personnel to design and build it, so that competent scientists will want to participate in the development and proper relationships can be established with scientists at academic institutions. Clearly, one of the major tasks of this advisory group would be to review the resources at our NASA field centers, and such other institutions as would be appropriate, against the requirements of the next generation of space projects and advise NASA on a number of key problems, such as: (1) How can we organize these major projects so that the most competent scientists and engineers can participate? (2) How can academic personnel participate and at the same time continue in strong academic roles? (3) What mechanism should be used to determine the scientific investigations which should be conducted? [4] (4) How does a scientist continue his career development during the six to eight years it requires to develop an ABL or a large astronomical facility? (5) Should we change the orientation of some of our NASA Centers? (6) What steps should be taken in scientific staffing, both inside and outside NASA, over the next few years to assure that we have the proper people at the proper places to do the job? (7) How can we obtain the competent scientists to take the key roles in these major projects? If you will undertake this job, we at NASA will work closely with you. Dr. Newell and the staff of the Office of Space Science and Applications will arrange any briefings which you desire, and will arrange for tours of the NASA Centers. We envision a group of astronomers, biologists, physicists, and geologists from both departments and administration in the universities. NASA would provide per diem and would pay the usual consulting fee. I will be glad to meet with you and discuss this further at your convenience. Sincerely yours, [signature] James E. Webb Administrator

[i] EXPLORING THE UNKNOWN 589 Document III-12 [cover letter] HARVARD UNIVERSITY DEPARTMENT OF PHYSICS LYMAN LABORATORY OF PHYSICS CAMBRIDGE, MASSACHUSETTS 02138 August 26, 1966 Mr. James Webb, Administrator National Aeronautics and Space Administration Washington, D. C. 20546 Dear Mr. Webb: The Ad Hoc Science Advisory Committee, which you asked me to assemble and Chair in your letter of January 14, 1966, has convened a series of meetings since that time and has prepared its recommendations. The Committee in its deliberations has been greatly assisted by members of the NASA staff, by participants in the NASA program, and by other individuals. The Committee herewith forwards its report. We believe that the changing nature of the National Space Program will create a multitude of new and deep questions of science, administration, and management. We have, therefore, made a number of recommenda- tions to help you in meeting these anticipated new problems. Please feel free to call on us if we can be of any assistance to you in the interpretation of these recommendations. Sincerely yours, [signature] Norman F. Ramsey, Chairman Ad Hoc Science Advisory Committee National Aeronautics and Space Administration ******** [17] G. Large Astronomical Facilities in Space Clearly, if NASA is to engage in a scientifically orderly development of a large earth- orbiting astronomical facility, which is a long-term undertaking of great cost, NASA needs the assurance of a continuing, responsible commitment from the scientific community towards this endeavor. Reciprocally, in view of the long-term character of this commit- ment, the scientific community needs the assurance of a reasonably strong role in the sci-

 entific direction of the program. The following plan suggests a mechanism to fulfill these two needs. Let us assume that the general plan of building a large multi-purpose space astro- nomical facility has preliminary approval, and then attempt to envision the various steps toward an orderly organization of the task. A legally constituted organization of universi- ties active or interested in the fields of optical, radio, X-ray, gamma-ray astronomy and other terrestrial radiations can be used. The Board of Trustees of this organization can appoint consultants who are representative of other interested persons and related research fields. The organization should be primarily designed to achieve the following: 1. A long-term commitment of the astronomical community, solidly based on insti- tutional commitments of a representative group of universities, to assist to the fullest extent required in the planning, design, construction, and use of an orbit- ing astronomical facility. 2. A means whereby leading astronomers can provide the necessary scientific direc- tion in the creation and use of the facility, while still preserving their university roles in research and education. [18]3. A means for securing international participation in the creation and use of the facility. The facility will take many years to build, and it should operate for a very long time-ground-based telescopes 60 years old still produce useful research. We conceive of the facility as a number of scientific instruments, most of them under common operational control, relatively closely grouped around a space station in an approxi- mately 200-mile orbit, so their scientific re-supply and engineering access is possible and economical. Earlier astronomical telescopes, including OAO, OSO, X-ray and other newer high-resolution telescopes, will provide essential, preliminary and con- tinuing experience. The corporate entity would provide continuity of scientific planning, instrumenta- tion, research and development, and programming. The function of this organization can be fulfilled either by an existing not-for-profit interuniversity corporation, or by a new one. In either case we shall, for convenience here, call the organization Space Telescopes for Astronomical Research, Inc., or STAR for brevity. STAR would obtain the best and most authoritative advice from the scientific community in defining the goals of the sci- entific program, and the details of the instruments that would become part of the scien- tific facility in space. STAR would develop preliminary specifications that would be transmitted to NASA Headquarters, which in turn would direct the appropriate field Centers to prepare alternative and competing designs and engineering approaches. Rival simultaneous and separated approaches in this phase seem desirable, considering the complexity of the problem; any apparent waste of manpower and time in this preparato- ry phase would be small compared to that in constructing and launching inefficient devices, because of the high costs of orbiting large payloads. A first-phase report prepared by STAR should be transmitted to NASA, and it should give the major scientific goals, con- clusions on [19] feasibility, and studies to indicate costs. STAR would work closely with NASA Headquarters, the NASA Centers, and the industrial designers to evaluate the designs and conduct trade-off studies.

 In phase two, let us assume that either one or more of the NASA Centers is assigned the management of the large astronomical facility. Its major instruments may include a large optical telescope, special -purpose solar telescopes, high-frequency radio telescopes, X-ray and gamma-ray telescopes, other radiation detectors, and possibly an associated space station. STAR would have an administrative, planning and small scientific staff at its headquar- ters. The Advisory Board of STAR would report its operations both to the member universi- ties and to NASA at a high level. In return, the STAR Board would be kept informed by NASA as to the direction the program is taking. STAR would also provide to the chosen NASA Centers continued scientific review. Because of the enormous complexity of the sci- entific and engineering problems involved, a close liaison must be maintained between NASA Headquarters, NASA Centers, and the engineering groups, contractors, and scientists in STAR. Although a NASA Center would be responsible for the construction of the major elements of the facility, certain sub-systems and scientific auxiliaries could be designed and built most efficiently by STAR, or by individual universities or scientists. The relative permanence of the principal elements of the facility places a heavy bur- den on its planning because further developments of astrophysical knowledge will affect the scientific goals. Maintaining continued close relations between the management Center and the university community will help to provide the most fruitful multi-purpose large astronomical facility. Above all, the design should be kept responsive to the scientif- ic goals, not only during the planning phases, [20] but also as late as possible during con- struction; also great care must be taken to ensure that the demands of engineering do not unduly compromise these goals. The sequence of devices to be built for X-ray astronomy will depend largely upon the present rapid advances in this field, and they will be better defined as observation and technology advances. Gamma ray astronomy, now in an early stage of growth, can also be integrated into the orbiting facility. A submillimeter or millimeter wave length radio antenna may be in the same orbit if scientifically justified, but a much higher orbit is required for a very low frequency, large radio telescope. Although physically separate, the latter, organizationally, belongs within the facility and STAR organization. Likewise, the STAR organization may be involved in providing the smaller orbiting telescopes that pre- cede the large one. The large orbiting astronomical facility will involve manned attendance with much hardware already available, possibly from the Apollo program, for re-supply, updating of sensors, repairs of defective modular subsystems, and recovery of photographic material. This is an essential operational feature because of the great cost of the large telescopes. The involvement of man would permit flexibility for future changes in the scientific pro- gram, would provide a closer link for cooperation between scientists and those interested in the continued development of our national capability for man-in-space, and would famil- iarize man with the problems of operating elaborate scientific devices under less difficult conditions than are normal in the smaller space vehicles of two or three man capacity. For the operational phase STAR would develop policy for allocating telescope observ- ing time to scientists from STAR, other universities, Government laboratories, NASA Centers, ground-based observatories, and to other interested scientists. The scientific pro- gram and definition of the operation policy of the telescopes, [21] including changes of subsystems, would be under the direction of the Board of STAR. Operational control of the facility, including engineering, re-supply, and safety, would be the responsibility of the NASA Centers. 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 inter- national cooperation. The nature of the orbiting observatory is such that participation in the scientific use and program of 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. It would hence be very valuable to make clear from the beginning that this unique facility, the orbiting observatory, is intended to serve astronomers on a world-wide basis, and to work out meaningful ways in which the world's most creative astronomers could participate and contribute to the scientific program. The extent or mechanisms through which international representatives should be involved in the management and planning of the observatory have not been examined. However, we believe that STAR could facili- tate the working out and operation of appropriate arrangements. Document III-13 Document title: G. C. Augason, "Manned Space Astronomy," NASA Headquarters, November 1966. Source: Space Telescope History Project, Archives, Smithsonian Institution, Washington, D.C. NASA's emphasis on human space flight in the 1960s affected nearly all of its activities, including the astronomy program. For example, Boeing's 1965 feasibility study for NASA on the Large Space Telescope the first extensive NASA-funded study on what became the Hubble Space Telescope— assumed that the observatory would be supported in various ways by human inhabitants of a near- by space station. Many other studies likewise considered the possibility of using humans in space to service or operate astronomical facilities. This NASA overview highlights many of these studies. [cover sheet] MANNED SPACE ASTRONOMY G.C. AUGASON NASA HEADQUARTERS NOVEMBER 1966

[no page number] EXPLORING THE UNKNOWN 593 MANNED SPACE ASTRONOMY SECTION I – EARLY EFFORTS Astronomy Subcommittee The purpose of this review is to recount the efforts made by the National Aeronautics and Space Administration (NASA) to use man in space as an aid in astronomical research. The Astronomy Subcommittee of the Space Science Steering Committee (SSSC) early anticipated the importance to astronomy of man in space. At the second meeting of the Astronomy Subcommittee, May 23-24, 1960, the role of man was discussed. J. A. O'Keefe was given the assignment of determining the effect of motion by the astronaut on observations. He reported in a later meeting that it was possi- ble for the astronaut to guide on objects which were several minutes of arc in angular sub- tense. At the fourth meeting, October 24-25, 1960, the fact that an astronaut could make useful observations was once again emphasized and it was stated that astronomical train- ing of the astronaut would be worthwhile. At the October 30-31, 1961, meeting an Ad Hoc Committee for Scientific Tasks for Man-in-Space was formed under the chairmanship of Dr. Jocelyn Gill. One of the tasks of the new committee was to develop a training program that would help the astronaut to make meaningful astronomical observations. [2] On February 20, 1962, the United States accomplished its first orbital launch when John Glenn made a three-orbit flight in the Mercury capsule, Friendship 7 (MA-6). In addition to his assigned tasks, Glenn made several observations which were of astronomi- cal interest. At the subcommittee meeting on February 25-27, 1962, it was proposed that an astronomer be present during the astronaut's debriefing to note and interpret any observation the astronaut had made. The Ad Hoc Committee for Scientific Tasks for Man- in-Space coordinated and reviewed experiments for the Mercury flights. Because of the space limitations, the lack of a suitable telescope, the lack of a large viewing port, and because of other demands on the astronaut's time, none of the experiments performed were of an astronomical nature. In subsequent meetings, one of the main areas of concern of the Astronomy Subcommittee was the role of man, his limitations, and his training and preparation. Attention was shifted from the Mercury flights to the Gemini-Apollo series in an attempt to have meaningful experiments ready for these flights. A careful set of ground rules was chosen for these experiments. In addition to fulfilling the space, weight and power limi- tations of the space capsule, and being of great value scientifically, the experiments had to be such that their performance was greatly enhanced by the presence of a man and/or some [3] portion of the experiment required reliable recovery. One of the main concerns at this time was that the observing port be of adequate size and have good transmission in the ultraviolet and visible. The February 4-5, 1963, subcommittee meeting was held at Houston at the Manned Spacecraft Center. The facilities were inspected and, in a detailed presentation, D. Slayton of MSC explained the training background and special problems of the astronaut.

 Manned Flight Experiments Working Groups Toward the end of the Mercury program, the Ad Hoc Committee for Scientific Tasks for Man-in-Space was disbanded and a Panel on In-Flight Scientific Experiments (POISE) was formed which was chaired by Drs. Gill and John O'Keefe. This panel was originally established to provide coordination between the Manned Spacecraft Center and in-flight experimenters. This panel reviewed over 100 experiments, 12 of which were then sent to the Manned Space Flight Experiments Board (MSFEB) and the Space Science Steering Committee (SSSC) for approval. Early in 1963 after the initial experiments had been selected for the Gemini flight program, POISE was discontinued. Subsequent manned space experiment review was performed by the regular subcommittees of the SSSC. A new group was formed consisting of flight experimenters, Manned Spacecraft Center person- nel, and NASA Headquarters personnel which is called the In-Flight Experimenters [4] group. Its purpose is to continue the coordination activities of POISE. This group was chaired by Dr. Gill and has been responsible for bringing about some improvements in the experimenters conditions on board Gemini and Apollo. A specific example is that of the Gemini observations port which is now protected during launch to prevent scratches and contamination from obscuring the pane. In order to provide coordination between the various subcommittees of the SSSC and manned flight experiments program, a committee was formed called the Manned Space Science Working Group. This committee was composed of a member of each of the sub- committees and was chaired by Mr. Willis B. Foster, the Director of Manned Flight Experiments in the Office of Space Science and Applications (OSSA). This group met twice, January 30 and March 26, 1964. The meetings were largely informative, i.e., for the purpose of explaining the manned space science programs. The main concern of the members of the group was with experiment opportunities on the various spacecraft and the methods which should be used to publicize these opportunities in the scientific com- munity. The group members as a whole were quite critical of NASA's apparent delay in doing this. Concurrent with the Manned Space Science Working group, separate disciplinary panels were meeting to determine the need and possible [5] experiments which might be performed using an Orbiting Research Laboratory (ORL). The Astronomy Panel met twice on October 26, 1963, and June 24, 1964. Dr. Peter C. Badgley of Manned Flight Experiments of OSSA presided and 18 astronomers and physicists attended who had demonstrated a previous interest in space astronomy. This panel set as its goal an 120-inch diffraction-limited telescope in orbit around the earth. The panel then formulated a gen- eral list of experiments to be performed with such a telescope. The panel noted in its rec- ommendation that a growing group of astronomers felt an urgent need for an immediate study of the detailed problems of manned space astronomy. They then delineated some of the specific problems expected. They felt that solutions to these problems should involve a large part of the astronomical community and that a consensus be obtained, although the panel did not know how to initiate such a program. Another group also met at this time to formulate experiments for the early Apollo missions. This was known as the Ad Hoc Working Group on Apollo Experiments and Training on the Scientific Aspects of the Apollo Program. This group, under the direction of Dr. Charles P. Sonett, had as its prime interest the study of selenography, planetology

EXPLORING THE UNKNOWN 595 and aeronomy. They published one report December 15, 1963. They considered the pos- sibility of the astronaut's doing astronomical experiments but concluded that “the initial Apollo missions should not [6] be burdened by astronomical activities." Apollo and Manned Space Station Studies At the May 23, 1963, Astronomy Subcommittee meeting, the members were asked their views on the scientific value of a manned space station. Most of the members felt that it was not justifiable at that time on a scientific basis, but that this might change once the limitations of unmanned observatories were determined. At the following meeting, August 8-9, 1963, Dr. L. Roberts of the Langley Research Center presented a report to the Astronomy Subcommittee on a feasibility study for a large manned orbiting astronomical telescope. The study had been carried out at Langley. Although the astronomical uses of the telescope generated by the study were felt by the subcommittee to be unrealistic, they felt it was a valuable study because the engineering aspects that were developed. It is necessary to know the engineering design parameters because these determine the constraints which must be placed on a related telescope. At the same meeting a representative from the Manned Spacecraft Center presented their long range plan for a Manned Space Station. At the November 7-8, 1963, Astronomy Subcommittee meeting, several proposals were reviewed for flight on Gemini spacecraft. The proposals [7] that were recommend- ed by the subcommittee were for a general purpose telescope by the University of Arizona; an X-ray astronomy proposal by the American Science and Engineering; and a proposal for the operation of a small fully stabilized telescope by Lowell Observatory. The advan- tages and disadvantages of a lunar-based observatory were compared with those of an orbiting platform at the May 6, 1964, Astronomy Subcommittee meeting. Also, at the same meeting, Dr. Harlan Smith made a report on the activities of the Manned Space Working Group. He described the method of selecting experiments for the Apollo program. This was done by approaching certain scientists directly. Then, at a meeting held at the MSC on June 15, 1964, the potential experimenters were to present their ideas for experiments. On August 11, 1964, a letter was sent out to many astronomers at various institutions, informing them of the opportunity to participate in the design of flight instruments and telescope systems which were larger than those currently scheduled and which would use a man in conjunction with these instruments. Those responding to this letter were to define the research objectives, to estimate the technical requirements to reach those objectives, and to identify engineering problems which would the demand particular attention. Essentially, the only response to this invitation was by Princeton University, with Dr. Lyman Spitzer as the principal investigator. Their proposal was for the design of a [8] diffraction-limited orbital telescope for direct imagery and ultraviolet spectrophotometry. At the time of the May 6-7, 1964, joint subcommittee meeting of the Astronomy Subcommittee and the Solar Physics Subcommittee, the following recommendation was jointly adopted: Both subcommittees resolved that it was their belief “that the vital part of both stellar and solar astronomy lies in the establishment of large astronomical observing equipment in space. This equipment should be a logical outgrowth of the currently planned OAO and AOSO programs and should utilize the best technology available at that time." At the October 28-30, 1964, meeting of the Astronomy Subcommittee, it was

596 NASA AND PLANETARY EXPLORATION decided that the subcommittee would review all proposals which had been submitted for a manned orbiting telescope in answer to a request for proposals originating with Dr. Leonard Roberts of the Langley Research Center. As a result of this invitation, the University of Virginia developed the astronomical objectives and requirements of a large orbiting telescope, the Fecker Division of the American Optical Company studied the optical feasibility of such a telescope and the Boeing Aircraft Company investigated the mission and engineering requirements. At this time considerable debate was occurring about whether the future needs of manned astronomy and science in general could be served [9] by adaptation and modification of the existing Apollo spacecraft system or if an entire new generation of spacecraft would be required. This problem was further complicated by the military requirements of the Department of Defense. In order to answer these questions, several industrial companies were funded to generate lists of manned scientific experiments which could be flown on Apollo. They were aided in this by several government panels. On February 1, 1965, an ad hoc panel was chaired by Dr. Henry Smith. The purpose of this panel, known as the Astronomy and Astrophysics Panel for Experiment Recommendations for the Earth Orbital Apollo Missions, was to review the astronomical experiments which had been proposed for Apollo. Dr. Smith's panel reviewed over two dozen experiments, fifteen of which were found worthy of flight consideration. These experiments were used as a planning basis for a post-lunar Apollo program which was to become known as the Apollo Extension Program (AEP). These experiments were later reviewed in detail by other reviewing groups. The AEP program, later to become known as the Advanced Apollo Program (AAP), will be discussed in greater detail under the section entitled Flight Experiments. [10] SECTION II - PROGRAM PLANNING Several alternatives were considered as possible manned astronomical programs to follow the Gemini and Apollo Lunar Missions. These alternatives required that a decision be made as to whether the Apollo Hardware could be modified to allow the accomplishment of future scientific requirements or would a new spacecraft have to be developed. This decision was further complicated by the requirement that NASA and the Department of Defense (DOD) might have to share the same vehicle. This choice was simplified when the President of the United States, on August 25, 1965, authorized DOD to develop a Manned Orbiting Laboratory for military use. This laboratory was to have a two-man crew and unmanned launches were to begin in 1968. The Air Force selected Douglas Aircraft Company, Inc., to build the spacecraft, with the General Electric Company being responsible for the experiments. The launch vehicle was to be a Titan 3C booster with a NASA Gemini capsule used for the return to the earth. With this decision, military requirements no longer had to be considered when developing a civilian manned space program. NASA chose to plan their future programs around the use of the modified Apollo spacecraft and this new series of missions was to be known as the Apollo-Extension Program (AEP), which later became the Apollo Applications Program (AAP). Following the AAP, it was assumed [11] that experiments would probably be done from a space sta-

EXPLORING THE UNKNOWN 597 tion orbiting the earth and for planning purposes this space station was named the Manned Orbiting Research Laboratory (MORL). The decision to use Apollo for the advanced manned scientific missions was based on the following reasons: first, the Apollo capsule was able to meet many mission require- ments as a result of the capability which was built into the Apollo system when the Lunar Orbit rendezvous mission was selected as the mode to be used for Lunar exploration; sec- ondly, the Apollo spacecraft would be a fully developed and tested vehicle by the time the AAP began; and third, the Apollo/Saturn system represented a national capability which might be lost if a program of this type were not developed for it. Once the decision had been made to pursue a manned astronomical observatory pro- gram based on the use of the Apollo hardware, the definition of particular missions was possible. In defining these missions the work of the previous panels, committees and work- ing groups was incorporated. Experiments which were previously planned for unmanned flight were reevaluated to see if they could gain by being flown in a manned environment. If the presence of a man would increase the lifetime or improve the reliability or reduce the signal bandwidth requirements, some of these experiments were reconsidered [12] for manned flight assignment. New meetings were held to help advise NASA in the for- mulation and priority assignment of different experiments. Many of these meetings were necessary because of the rapid advances which had been made in several areas of astron- omy because of the use of unmanned vehicles. X-ray and gamma-ray astronomy are exam- ples of such rapidly progressing subdisciplines. In addition, new invitations went out to publicize the new opportunities for experiment. An invitation describing the advanced Apollo missions and the opportunities for experiment was sent out to many potential experimenters March 11, 1966. Studies by the National Academy of Sciences Space Science Board Meeting, Woods Hole, Massachusetts. An important meeting in the NASA planning process was held under the auspices of the Space Sciences Board of the National Academy of Sciences at Woods Hole, Massachusetts, on June 20 to July 16, 1965. A report of this meeting entitled “Space Research, Directions for the Future," defined the scientific objectives which should be achieved and made recommendations on how they could be accomplished. The broad research objectives for astronomy were defined as: "(1) Is the Universe finite or infinite, and if it is finite, what is its size? (2) Is the Universe in a steady state, and if not, how did it begin and how will it end? [13] (3) Do the laws of physics as deduced on the Earth apply without change for all times and overall distances? Alternatively, are there fundamental physical laws or phenomena still undiscovered in terrestrial laboratories, that are observable only on an astronomical scale? (4) Were the chemical elements that form all matter built up out of hydrogen, and if so, how? (5) How are stellar systems, stars, and planets, formed?" Their general conclusions were that: 1) Successful study of the planets will require the presence of scientists, either on the planet's surface or orbiting the planet because of com- munication time delay and/or power bandwidth requirements. 2) Man may be success-fully employed in space as an observer; for assembly, placement, repair and operation of scientific instruments; for analysis, collection, storage and retrieval of data. 3) The cost of manned space flight can not be justified on the basis of its “scientific value" alone. The working group visualized four types of programs: 1) The current Gemini and Apollo programs; 2) More advanced laboratories such as the Apollo Applications Program (AAP); and 3) Large, special-purpose space laboratories such as optical, radio, X-ray or gamma-ray observatories. Both the optical and solar astronomy panels made recommen- dations that the AAP be utilized as an interim program to gain [14] experience with tele- scopes in the 60- to 80-inch category with a goal of a manned orbiting telescope (MOT) with a 120-inch diameter mirror and usable in the 500 A to 1 mm spectral region. Space Science Board - Large Space Telescope Panel. A large national facility was recommended strongly by the Woods Hole Summer Study and other panels and com- mittees. Although such a facility has been given various titles and it may be lunar rather than orbital, NASA has come to call it MOT (for manned orbiting telescope). As recommended at the Woods Hole meeting, a panel under the chairmanship -of Dr. Lyman Spitzer, Jr., of Princeton University has continued to hold meetings to discuss the problems involved in developing a large space telescope (April 29-30, 1966, and July 17-19, 1966). In their meetings they have considered the scientific program, tech- nical problems and managerial problems. The last meeting mentioned was devoted to developing the scientific objectives in detail. The scientific recommendations of the Woods Hole meeting have been used as guidelines. The committee has accepted the recommendations of NASA as regards the largest diameter mirror which can be placed in orbit with the present generation of launch vehicles. They believe it is rea- sonable to assume that such a mirror (120 inches in diameter) may be made diffrac- tion-limited. If this is not possible, they would prefer to sacrifice the diffraction limitation to total aperture. *** ***** [22] NASA Headquarters OMSF. The Office of Manned Space Flight supported a major study by the International Business Machines Corporation entitled, “ORL Experiment Program,” under Contract NRSw-1215. The ORL (Orbiting Research Laboratory) con- cept is a general one which included many disciplines. This study had as its very com- mendable goal the determination of experiments to be performed by man in space. This goal was not to be accomplished from the “bottom up" by selecting a list of exper- iments compiled from submissions by interested experimenters but rather experiments would be chosen on the basis of their ability to answer fundamental and important ques- tions in a particular discipline. IBM pointed out the following shortcomings in the “bot- tom up" approach: "a. It results in a collection of individual tests, rather than in a cohesive program; the interrelationships of the individual experiments and the extent of their overlap are obscured. b. It lacks a rationale to determine whether the most important experiments have been identified and are being pursued.

EXPLORING THE UNKNOWN 599 c. Few of the suggested experiments are explicitly tied to requirements or ultimate benefits; as a consequence, the resulting [23] programs frequently fail to demon- strate the value of the space station vis-a-vis its cost." Under the Astronomy/Astrophysics discipline IBM defined four main objectives, many subobjectives and 132 knowledge requirements. This list of experiments has been used as a guide on occasion for various studies, although it is incomplete and sometimes trivial. North American Aviation, Inc.: Under Contract NAS 2-1047, North American Aviation did a study of "The Lunar Exploration System for Apollo" (LESA). The purpose of this investigation was to develop a description of scientific operations that can be car- ried out on the moon with LESA. The LESA system includes a family of prefabricated modules that can be assembled on or below the lunar surface in a variety of arrays. Recommended scientific investigations were obtained from each of nine -panels. Three of the panels which considered astronomical experiments were: Optical Astronomy, Radio Astronomy and Wave Propagation, and Radiation which treated Ultraviolet, X- and Gamma-Ray, and Neutrino Astronomy. The various experiments were divided up to be performed on early and on late missions. In case of Optical Astronomy the early mission would use a 40-inch lunar--based telescope for multihour exposures. The later missions would employ a 120 inch instrument. Langley Research Center. Langley Research Center, an Office of Advanced Research and Technology (OART) center took an early interest [24] in the problems associated with manned astronomical experiments in space. Most of their studies were done by con- tract under Associate Director, C. J. Donlan. This work was carried out by P. Hill who head- ed the Manned Orbital Research Laboratory (MORL) Steering Committee, Dr. L. Roberts who was in charge of the Manned Orbital Telescope (MOT) Steering Committee, and W. Gardner who headed the MORL Study Group. The Langley people came to the conclusion (based on their early studies) that a tele- scope employing a 120-inch mirror which had the structural integrity to be diffraction lim- ited was the largest telescope which could be launched on the Saturn series of vehicles. This determination has been generally accepted in all other studies. Douglas Aircraft Co.: One of the earliest studies was that by Douglas Aircraft Co. with International Business Machines (IBM) as a subcontractor. This study was initiated by the MORL Study Group and was completed January 1966. Its purpose was to define and optimize typical missions using MORL. This study was accomplished in three phas- es: Phase I (June-September 1963) System Comparison and Selection Study of a Manned Orbital Research Laboratory; Phase I A[sic; should be IIA] (December 1963 - November 1964) Optimization of the MORL System Concept and Phase II B (December 1964 - January 1966) Development of the MORL System Utilization Potential. Phase I demonstrated the feasibility of launching, operating, and maintaining a manned research laboratory. Phase II A defined the MORL concept [25] to include a (1) 260 inch dia. laboratory launched by the Saturn IB in a 200 nautical mile orbit inclined at 28.72º to the equator; (2) a Saturn IB launched Apollo logistics spacecraft and; (3) supporting ground systems. Phase II B examined experiments from NASA, and Department of Defense (DOD) sources redefined them and collated them, and commonality was searched for. This was done to determine the utilization potential of the MORL system concept.

 University of Virginia: The MOT Steering Committee supported an investigation by Dr. Laurence W. Fredrick of the University of Virginia entitled, “Applications in Astronomy Suitable for Study by Means of Manned Orbiting Observatories and Related Instrumentation and Operational Requirements." The resulting report considered the following areas appropriate for research with a MOT: Stellar Mass Determination: The ability of an orbiting telescope to determine mass depends on (a) the theoretical resolu- tion limit and (b) the accuracy of guiding during exposure. With a guiding accuracy of only 0.3 seconds of arc, masses of at least 30 new binaries may be determined. Cosmological Tests: The concept of uniformity in general relativity may be tested by an intercomparison between brightness distances and size distances. High Resolution Photography and Spectroscopy: Photography with the resolution possible in space is important to all fields of astronomy. Increased spatial resolution will allow increased spec- tral resolution which is needed in all spectral regions. Infrared Observatories: Because of the longer observing times available and low sky temperatures, infrared observations from a MOT should be two orders of magnitude better than observations from a comparable telescope on earth even in the [26] windows and of course infinitely better in the opaque portions of the atmosphere. Measurement of stellar diameters: Interferometric and image orthicontechniques on a MOT should allow stellar diameters to be measured down to 0.0005 seconds of arc. The Study of Regions of Polarization: Techniques which have been used to study polarization in the visual spectral region could be extended to other spec- tral regions. The Search for Very Faint Stellar Companions: An apodizing device could be constructed for a MOT which would not increase the definition of a star but would enable close faint objects to be detected. Integrated Studies of Comets: The large aperture of the MOT would allow studies of comets to be made as they become fainter after leaving the sun and long intergarion times would not be needed. Also comets could be observed in all spectral regions and their behavior monitored. American Optical Company: In 1964 the MOT Steering Committee funded the J. W. Fecker Division of the American Optical Company at Pittsburgh, Pennsylvania, to do a "Feasibility Study of a 120-inch Orbiting Astronomical Telescope” report AE-1148. They looked at the optical problems involved. They did ray tracing and developed some optical configurations. They chose a cassegrain configuration with an f/2 parabola for the pri- mary mirror which could be used with different optical components to give a range of focal ratios from f/2 to f/100. Although their design was not optimized they felt that they had demonstrated feasibility. One of the most severe problems they encountered was maintaining the alignment of the secondary mirror, but they felt this could be accom- plished by the use of an active system [27] with a laser and interferometric techniques. Boeing Aircraft Company: The University of Virginia and American Optical Company studies served as a starting point for a rather thorough study by the Boeing Company of Seattle entitled "A System Study of a Manned Orbital Telescope" D2-84042-1, October 1965 and a continuation, “Synchronous Orbit Study” D2-84042-2, April 1966. General Electric was retained as attitude stability and control subcontractor and Drs. Zdenek Kopal of the University of Manchester, and James G. Baker of Harvard served as consultants. This report did much to establish the 120 inch telescope as the largest size which could be launched. The limiting stellar magnitudes presented may be too bright by as much as five magnitudes.

EXPLORING THE UNKNOWN 601 The principal results of the Boeing Study were: Astronomy and Optics-The astro- nomical objectives of The Virginia Study were accepted almost in total. A Ritchey-Chretein modification of the pure Cassegrainian System was selected with an f/4 primary and two secondary mirrors which permit operation of the telescope at f/15 and f/30. Necessary instrumentation was designed conceptually. Operations Analysis—The role and contribu- tions of man were carefully delineated. The study of the operation of the MOT was nar- rowed down to three basic modes which used the MOT in conjunction with the MORL as defined by Douglas in their study. The preferred modes were a detached mode capable of docking with the MORL but employing a shuttle for normal operations and a soft [28] gimballed mode. Configuration■ Various configurations were examined. Launch and orbital configurations for the two select- ed modes of operation were developed. Scientific instrumentation and cabin arrangement for the MOT were also defined. Structures—The primary structural design was based on the boost condition. Special attention was given to the primary mirror stresses during the boost and docking, the dynamics of the soft gimbal made, thermal distortions of the primary mir- ror during operation and meteoroids and radiation. Attitude Stability and Control-The observational requirements were used as the basis from which to synthesize an attitude con- trol system. The study showed that it would be feasible to stabilize the telescope to within 0.01 seconds of arc. A pointing error for the soft gimbal concept of about 0.003 seconds greater than for the detached mode was indicated. Thermal Analysis-Computer studies were per- formed to determine the thermal gradients in the primary and secondary mirrors and the telescope structure. The use of an earthshade and doors that closed when the optics were pointed towards the earth greatly aleviated [sic] many thermal problems. The general conclusions were that the MOT was a feasible system and that the soft gimbal mode would be preferable. A synchronous orbit is feasible and it would allow longer observation times with reduced thermal problems. In addition to the above, Boeing outlined several special problems including optics manufacture, film handling an [sic] attitude stability control. Marshall Space Flight Center. The Marshall Space Flight Center (MSFC) has sup- ported studies to develop programs to follow the early Apollo lunar missions and which would utilize the talent and hardware which were developed for Apollo. ******** [43] The Manned Orbiting Telescope (MOT) The term “manned orbiting telescope" has been used rather ambiguously in NASA. It originally referred to any program which employed a telescope and utilized a man to set it in operation and to maintain and operate it. It was usually assumed that this telescope was in an earth orbit but telescopes operating from the moon have also been considered under this title. More recently the designation MOT has been reserved for telescopes not connected with AAP. Earth orbiting telescopes connected with AAP are now called ATM and MOT is reserved for another generation of missions. In recent usage, MOT also refers more specifically to a major national astronomical facility in space. In addition to the MOT studies referred to in Section II, NASA Headquarters has made two additional studies. The first was “The National Astronomical Space

602 NASA AND PLANETARY EXPLORATION Observatories Working Group Report," August 16, 1966. This report was generated for the Planning Coordination Steering Committee of NASA Headquarters. This document describes the major astronomical problems that exist and then describes how a 120--inch diffraction-limited telescope would help find the answers to these problems. It has been thought by many that, to be most effective, at least one and perhaps several astronomers will have to spend their full time with MOT. In order to support these astronomers some sort of a space station will be required. A study has been made of space stations and [44] their associated problems which is entitled “The Needs and Requirements for a Manned Space Station," September 28, 1966. This report was prepared by the Space Station Requirements Steering Committee, and dis- cusses in depth the justifications for a space station; an MOT is one [sic] the more important justifications. Document III-14 Document title: NASA Management Instruction 1156.16—“NASA Astronomy Missions Advisory Board," September 25, 1967. Source: NASA Historical Reference Collection, History Office, NASA Headquarters, Washington, D.C. Document III-15 Document title: NASA, “A Long-range Program in Space Astronomy, Position Paper of the Astronomy Missions Board,” NASA, edited by Robert O. Doyle, Harvard College Observatory, July 1969. Source: NASA Historical Reference Collection, History Office, NASA Headquarters, Washington, D.C. While it did not immediately embrace the idea of establishing an external organization to manage the scientific operations of a space-based astronomical facility, NASA's head of space science, Homer Newell, in reaction to the Ramsey report, suggested creating a standing group of academic astronomers to advise NASA on astronomy program objectives and strategies. The new group, the Astronomy Missions Board (AMB), was chartered in 1967 to address astronomy needs, just as the Lunar and Planetary Missions Board supported the solar system exploration program. In July 1969, the AMB issued a long-range program in space astronomy, outlining the most pressing prob- lems and the types of observations and instruments necessary to solve these problems. After more than two years of meeting regularly, after preparing this report the AMB ceased functioning because of board members' frustration that NASA never acted on its recommendations due to lack of funds to conduct suggested programs.

[1] EXPLORING THE UNKNOWN Document III-14 Management Instruction 603 NMI 1156.16 September 25, 1967 Effective date SUBJECT: NASA ASTRONOMY MISSIONS ADVISORY BOARD 1. PURPOSE This Instruction establishes the NASA Astronomy Missions Advisory Board and sets forth its functions and scope of interests. 2. AUTHORITY a. Section 203 (b) (7) of the National Aeronautics and Space Act of 1958 (42 U.S.C. 2473 (b) (7)). b. Executive Order 11007 (February 26, 1962). C. NMI 1150.2. 3. ESTABLISHMENT a. (1) The NASA Astronomy Missions Advisory Board (hereafter referred to as the "Board") is hereby established to assist NASA in the planning and conduct of all NASA missions to create and operate astronomical telescopes in space. (2) The long-range continuing objectives of astronomy are to learn by remote observation the structure and behavior, the origin, growth, and demise of all types of celestial bodies, ranging from the smallest (meteorites, comets, and planets) to the largest, including stars, star systems, the matter in space, and the entire cosmos. The telescopes utilized by space astronomy work over the whole range of the electromagnetic spectrum, from gamma rays, through X-rays, the ultraviolet, visible light, infrared light, and radio frequency radiation. (3) Excluded from the Board's area of responsibility are missions to study the moon and planets from a close vantage point, or in earth orbit for study of the earth. b. Pursuant to Executive Order 11007 and paragraph 6 of NMI 1150.2 it has been determined that the formation and use of the Board is in the public interest. The Board is not an “industry advisory committee” within the meaning of para- graph 5b of NMI 1150.2.

604 NASA AND PLANETARY EXPLORATION [2]4. FUNCTIONS The Board will serve in an advisory capacity only. Organizationally, the Board will be responsible to the Associate Administrator. Determination as to any action to be taken which is based in whole or in part on proposals or recommendations of such Board shall be made solely by appropriate full-time salaried officials or employees of NASA. The scope of the Board's activities include, but are not limited to: a. b. C. d. e. f. The development and review of the scientific objectives and general strategy for space astronomy and associated ground-based astronomy. The review of support of ground-based astronomy and observations from sounding rockets, balloons and aircraft as well as satellites. The formulation of guidelines and specific recommendations for the design of space astronomy missions, and for the various telescopes and auxiliary equip- ment to be developed and used on these missions. The continuing review of the way these missions are meeting the needs of cur- rent scientific objectives and strategy. The continuing examination of policies relating to the operation of these tele- scopes in the space observatory once they have been made operational and are available for observations by the scientific community. The development and improvement of mechanisms by which the NASA space astronomy program can get the best assistance from, and give the most help to, the entire community of astronomers and space physicists. 5. MEMBERSHIP a. b. The Board shall be composed of about 12 scientists and engineers, all of whom are broadly experienced in the technology and scientific discipline of astrono- my. To be proportionately representative of the astronomical community at large, the membership majority will normally not be made up of full-time NASA employees. The Board Chairman will be designated from among the non-NASA members of the Board. The Board will also have an Executive Director who shall be a full-time salaried employee of NASA, but who will not be a member of the Board. The Board and its Chairman will be appointed by the Administrator, and will serve at his pleasure. The Executive Director will be appointed by the Associate Administrator. The Administrator will consult with the Board on any appoint- ments to the Board. 6. BOARD RELATIONSHIPS a. The Board will have a close working relationship, through the Associate Administrator, with senior NASA officials and organizational elements involved. Requests for advice and recommendations will be made to the Board through the Associate Administrator. Similarly, the Board will request studies or other

EXPLORING THE UNKNOWN 605 assistance required from other groups in or out of NASA through the Associate Administrator. Document III-15 [cover sheet] NASA SP-213 A LONG-RANGE PROGRAM IN SPACE ASTRONOMY Position Paper of the Astronomy Missions Board July 1969 Edited by ROBERT O. DOYLE Harvard College Observatory Cambridge, Mass. [iii] PREFACE The Astronomy Missions Board was established by the National Aeronautics and Space Administration by charter in September 1967 to assist in an advisory capacity in the planning and conduct of all NASA missions to create and operate astronomical experi- ments in space. The scope of the Board's activities includes development and review of the scientific objectives and general strategy for space astronomy and associated ground-based astronomy; the formulation of guidelines and specific recommendations for the design of space astronomy missions, and for the various experiments and auxiliary equipment to be developed and used on these missions; the continuing examination of policies relating to the operation of these space observatories once they have been made operational and are available for observations by the scientific community. The work of the Board encom- passes the many aspects of space astronomy including direct observations of electromag- netic radiation from astronomical sources, cosmic-ray particles and the supporting research that is necessary, but its scope does not include the study of the Moon and plan- ets from close vantage point or study of the Earth.

 The Astronomy Missions Board is presently composed of 18 members of the scien- tific community with a wide diversity of interests and experience. They are drawn large- ly from universi-ties, but include members from national laboratories (see appendix for a list of members of the Board and its panels) [appendix not included]. The Board's activities are supported and supplemented by seven panels and two ad hoc working groups to whom specific areas of responsibility are assigned. The panel compositions are similar to that of the Board itself and involve an additional 31 scientists. This wide membership provides a broad representation of current thought in space astronomy both directly through its membership and from the wider astronomical community by means of letters and discussions. The activity of the Board has been intensive. With few exceptions, it has met month- ly for 2 days at locations appropriate to its current activities. In addition to extensive delib- erations and [iv] discussions, the meetings have included reports and resumes from NASA personnel about matters such as the current status of projects then underway, present NASA plans for the future, technical reports on areas of special relevance, and bud- getary aspects of current and planned programs. The panels have met several times dur- ing the past year and have taken the opportunities for obtaining firsthand information about the activities in space astronomy at various NASA centers relevant to their particu- lar fields of interest. Again, briefings as to technical capabilities and current planning were obtained and the panels prepared detailed programs and recommendations for activities in their areas. An important continuing activity of the Board is the presentation of specific recom- mendations to the Associate Administrator of NASA. Many of these recommendations have been ad hoc answers to questions raised by NASA, while others have been of a more general nature and have, in most cases, been incorporated into the body of this report. Many of these ad hoc recommendations were for the purpose of assisting NASA to opti- mize a low-level program, and should not be construed as approval of such a program by the Board or the scientific community. The Board has created a long-range national program for space astronomy-including discussions of the major problems of astronomy and astrophysics, an observing program describing the next important measurements from space, and examples of the instru- ments, spacecraft, and missions needed to make those measurements. Specific mission descriptions are not intended as concrete definitions of future missions, but as part of an exemplary program which is used to establish the best current balance between the sub- disciplines. The plan contains sufficient mission priorities and interdependences on which to base AMB advice to NASA at various foreseeable levels of effort, and should enable NASA management to assess the impact on scientific progress of the various future options available to them. The purpose of this position paper is to describe the long-range plan as it appears in July 1969. Past experience has shown that astronomy is a field full of surprises and the unex- pected, and it would be extremely shortsighted to expect this report to remain up to date for very long. This report is not intended to be a static document. It is, rather, a working paper to be updated and altered continuously by the Board as technical capabilities change and scientific opportunities and priorities evolve. Nevertheless, it seems appropri- ate to publish [v] this version of the position paper, just as it was submitted to NASA as

EXPLORING THE UNKNOWN 607 part of the fiscal year 1971 budget planning cycle, in order to acquaint a wide communi- ty of astronomers, astrophysicists, physicists, and other interested scientists with the work- ings of the Astronomy Missions Board, as well as with the national space astronomy program. NASA and the Astronomy Missions Board hope in this way to continue to improve the mechanisms by which the NASA space astronomy program can get the best assistance from, and give the most help to, the entire community of astronomers and space physicists. From time to time, as the extent of the revisions makes a major part of this work obsolete, the Board will again publish an updated position paper. The detailed reports on the subdisciplines of space astronomy, authored by the pan- els and endorsed in substance by the Board, will be found in Part II[not included]. Part III describes how the panels' programs were evaluated, and how parts of them were com- bined into long-range plans at two levels of effort-a minimum balanced program and an optimum program-both of which do not attempt simply to do everything suggested by the subdisciplines, but rather emphasize research on those problems judged astrophysically most important by the greatest consensus of the Board. A summary of the position paper and key features of the long-range plan will be found in Part VII [not included]. ******** [223] III AMB LONG-RANGE PLAN FOR SPACE ASTRONOMY [227] THE TWO AMB LONG-RANGE PLANS Before presenting the final mission schedules, we should briefly define each of the long-range plans-describing the characteristics that the AMB hoped to impart to these composite programs. The Minimum Balanced Program The definition of a minimum program, especially the concept of a sharp break below which progress becomes substantially more difficult if not impossible, is often an exercise fraught with the possibility of misunderstanding. We therefore emphasize the significance of the AMB minimum balanced program as that level below which one or more of the sub-disciplines of astronomy must be dropped to maintain the others above their minimum thresholds of efficient and scientifically profitable operation. Such a negative step would then seriously undermine a central assumption of the Board's planning; namely, that the agreement between the subdisciplines on the most important astrophysical problems requires an orchestration of the multiwavelength observing programs. This assumption is that for many problems a few relatively unsophis- ticated, and sometimes less expensive, measurements in different wavelength regions might lead to a deeper [228] understanding of the physics of a process—than a most beautiful detailed picture achieved at great cost at a single wavelength. This is not to say that in some cases the narrow, highly specialized approach might not produce the essen- tial, even indispensable, key. It is simply a judgment of the Board about the requirements for greatest progress in most problems before us at the present time. We should also note in passing that the Board found it was often these problems requiring a multiwavelength, multidisciplinary approach, which are the problems attracting so many physicists and sci- entists from other disciplines to come to work in modern astrophysics. A timely example of the lengths to which scientists will go to achieve the completeness of the multiwavelength approach, and an illustration of the uses to which the future capa- bility in space astronomy will be put, is the current standby alert trying to catch the bril- liant flash of a flare in the X-ray star, Sco XR-1. Starting in May, astronomers at Cerro Tololo Observatory in Chile have been continuously measuring the visible radiation, watching for the onset of a flare. At the first sign of activity, they will radio other astronomers at Caltech where the 200-inch Mount Palomar telescope will make infrared observations, in Hawaii where a rocket will be launched to record the X-ray spectrum, and at Goddard Space Flight Center where University of Wisconsin experimenters will turn the Orbiting Astronomical Observatory's ultraviolet telescopes toward the X-ray star. Since the Australians recently discovered Sco XR-1 to be a strong variable at radio wavelengths, a large steerable radio telescope may also be used to complete the wavelength coverage. The great hope is to achieve several measurements whose combined value in terms of sci- entific understanding might greatly exceed the combined cost relative to that of any one of the measurements standing alone. The Optimum Program Although the concept of an optimum program is usually less controversial than a min- imum program, the Board wants to take pains to stress that this is not simply a program in which the subdisciplines all are encouraged to do their maximum unconstrained pro- grams. First, it was composed from a set of subdiscipline maximum programs where the principal constraint, or upper limit, was the projected availability of excellent people-sci- entists and supporting teams of specialists-to carry out the recommended missions. Second, the level of the resulting optimum Board program was about 20 percent below the sum of the maximum subdiscipline [229] Finally, the Board's priority assignments again raised and lowered the levels of the individual programs to accomplish a unity and balance with prospects for greatly multiplied combined benefits. FLIGHT SCHEDULES On the following pages we present the schedules of space astronomy missions which implicitly contain the best judgment of the Astronomy Missions Board concerning the present optimum balance of effort between the various subdiscipline programs, as those programs were described in part II. These schedules cannot be adequately interpreted without recourse to the subdiscipline reports where the observational programs and mission objectives are developed. We present here a brief description of the structure of the schedules and a glos- sary of terms and abbreviations which will assist the reader in referring back to a particu- lar subdiscipline report for further information. The minimum balanced program flight schedules are shown in table 1 (Astronomy Missions) and table 2 (Space Physics and Interplanetary Missions). The optimum programs are shown in tables 3 and 4. The gen- eral plan of the Astronomy Tables 1 and 3 shows increasingly expensive types of missions arranged vertically in successive blocks. Each block contains spacecraft which are approx- imately a factor of 2 more expensive than the preceding block. Within each block one row

EXPLORING THE UNKNOWN 609 is given to each of the subdisciplines, with one exception (X-X and g■ray, O■Optical UV and IR, R-Radio, S-Solar, P-Planetary). [230] Darkne TABLE L—Minimum Balanced Program-Astronomy _ .... - barb wyalchi platform-$131/vzul 141414141414141 " ± ** --- - ur ■■■■ ■ 080-7 65-06-1 10-mu F +Part L ■ IÓ-2 DIO-q ▲ LONG-BANG. PROGRAM IN SPACE ASTRONOMY TABLE 2. „Minimus Program for Fields and Portiels Astronomy (Astronomy Portion) Beach (Lat Me (Explo/poletis pel). Over Bankma", (la pecin t■ "a pinnak (1) La valythe phone. (3) of adliyija plan■. (a) Marko Mar (we Ying) Jaz Pro (4) Tamara Fal (3) Q/11. miez prob [er past■ to 11 AU…. Large bed experienta (or Apa Applications wit plangens Y 1)M Rockle T IL N.O | 7.9|21|20| VW LY ■ G.D H " " M 10 14 A- ▲ 2,0 b -- " Gaze 5.| DIE -------TT. H (l) DT -

 ******** [234] X-Ray and y-Ray Missions Balloons.—Continued pointed flights—y-ray continuum studies■reach 103 CM2 sec1 level at 105 eV for selected X-ray discrete sources. Rockets. Broad participation-quick turnaround. Explorers.-SAS-A: sky survey sensitivity 104 Sco X-1; 1-8 keV, 0.5° resolution, broad- band spectral resolution; SAS-B: high-energy y-ray survey 106 CM^2 sec^1; SAS-C and beyond: extend energy response 200 eV to 1 MeV, larger spark chamber devices, improve pointing to study sources, time variations. OSO. Continued use of wheel section for surveys, monitoring. OAO or equivalent.—First stellar X-ray imaging telescope positions to -1 arcsec, 2/2 to ~ 0.01 for sources to 104 Sco X-1. Instrumentation state of art. OWSE.■High-sensitivity X-ray and nuclear - g-ray surveys, nuclear lines and continuum studies; large Cerenkov telescopes, 108 CM^2 sec^1 above 500 MeV, crude energy resolution. Heavy Explorers.-A: high-sensitivity X-ray survey 10° Sco X-1, 0.1° resolution, nuclear y-ray survey chamber 107 cm^2 sec^1, Cerenkov telescope; B: extend sensitivity, broad ener- gy resolution, increase angular resolution-study continuum y-rays from known extra- galactic X-ray sources. OXO.—Stellar X-ray imaging telescopes, design goal -1-m aperture, interchangeable instruments at focus to accommodate image detectors, polarimeters, spectrometers. 5-10-m X-ray telescope.—A permanent National Space Observatory. Optical Highlights Structure and processes in the outer atmospheres of stars—especially extremes such as very hot, very cold, and very unstable objects-hold clues to the history and fate of stars. Stellar spectrophotometry in the UV can give information on such stellar chromosphere and coronas, adding to our knowledge of similar solar activity which controls solar-inter- planetary-terrestrial relationships. Absorption line measurements in the UV are three orders of magnitude [235] more sensitive than visible lines in detecting the interstellar gas, helping to determine chemical composition, physical state, and energy balance of the interstellar medium. Continuous spectrophotometric measures of planetary atmospheres, comets, and the interplanetary medium will help us to understand the origin and present nature of our planetary system. Spectrophotometric UV and IR observations of gas ejection from galactic nuclei, together with high-resolution images of these objects, will help unravel these explosive events whose extreme dynamic conditions play a fascinating role in the evolution of stel- lar systems and which may lead to new knowledge of fundamental physics. Optical Missions Airplanes and balloons.-IR telescopes, from 36 inches in minimum program to a pos- sible 120 inches in maximum; balance flights between large platforms such as Convair 990 and smaller single experiment flights such as Lear Jets. High-resolution visible telescopes (Stratoscope).

 Rockets. UV spectrographs, 1-X resolution, for studies of stellar atmospheres and interstellar absorption lines. Possible standby for a bright comet. Far IR broad-band scan of sky for emission from interstellar dust grains and sources with peak intensities at wavelengths greater than 20 m. SAS.■Broadband UV photometer and polarimeter, selective extinction and polariza- tion by grains, variable stars and galaxies, solar-system objects. UV sky survey.—Interstellar gas emission at several wavelengths. IR telescope. Probably refrigerated-10-100 m for the study of planets, stars, gas, grains. OAO-B (GSFC).—UV scanning spectrometer 2-X resolution, stars and nebulae; OAO-C (Princeton) UV scanning spectrometer 0.1- and 0.4-Å widths, interstellar absorption in stars to 6th magnitude, stellar spectra; OAO-D (national facility): UV scanning spectrom- eter with offset guidance, 0.3-0.5 Å width, spectra to 8th magnitude, 40-Å resolution to 13th magnitude; OAO-E (National): wideband UV spectrophotometer and polarimeter, offset guidance, galaxies, variable stars, interstellar grains; OAO-F (National) UV echelle spec- trometer with integrating TV tube, width 0.1 Å to 9th magnitude, 100 Å to 18th magnitude; OAO-G (National): IR interferometric spectrometer plus broadband IR photometer, light-weight cryogenics system, later flights include improved versions of E, F, and G. Astra.■A: UV echelle spectrometer, high-resolution imagery with filters to magnitude 26 in visible; B: more flexible instrumentation; C: include IR capability. Large space telescope.-Aperture 120 inches or more with resolution corresponding to 120 inches, indefinite life. See LST report of the National Academy of Sciences. Infrared Highlights Infrared detector technology and infrared astronomical discovery are together under- going revolutionary developments in which there are increasing advantages in making observations outside the atmosphere. Infrared space observations will permit-■ (1) Observations of extended faint objects. (2) Observation in the five octaves of spectrum from 25-700 m. [237] (3) Broadband observations of extremely faint objects with detectors limited only by celestial radiation. Fields of study already known to be able to profit from these capabilities are■ (1) The stellar and dust structure of our galaxy. (2) High-energy processes that occur in some galactic nuclei and quasars. (3) The role of dust envelopes in the evolution of stars. (4) The role of dust envelopes in the formation of, planetary systems around young stars. (5) The thermal mission and heat balance of planets and the Moon. (6) Infrared background radiation. High-temperature phenomena at remote epochs will have their radiation shifted into the infrared. Thus these studies have poten- tial cosmological significance. Infrared Missions Because of the rapid development possible in detector technology, and the high rate of discovery of new classes of astronomical infrared phenomena from the ground, a major effort must be made in these areas to insure that full possible benefit is obtained from the space observations.

612 NASA AND PLANETARY EXPLORATION Significant developments are expected to occur from the use of small high-altitude aircraft, small balloon-borne equipment, and some rocket flights. Major installations appropriate for the next few years include a 36-inch telescope to be used in a stratospheric airplane primarily for point source observations, and a Small Astronomy Satellite to be used for studies of extended objects and for surveys for new objects. Eventually, technological advances and astronomical discoveries may slow down, and it will be necessary to use larger platforms such as an OAO or a Large Space Telescope. Should detector improvement be difficult, this phase would come earlier. Radio Highlights Measure the flux densities of 50 to 100 extragalactic and galactic sources at a number of frequencies around 1 MHz. Map the cosmic background noise level of the full sky at a number of frequencies from 0.5 MHz to 10 MHz. Measure dynamic radio astronomical phenomena and, in particular, record variations of radio emission from the Sun, Jupiter, and other variable radio sources. Measure the brightness distribution across a few individual radio sources which are occulted by the Moon. Obtain data on the statistical parameters of cosmic background noise fluctuation at a few frequencies near 1 MHz. Study variable interplanetary absorption and interplanetary scintillation effects. Solar-system observations will concentrate on understanding physical processes in the solar corona and in the magnetospheres of the planets, especially Jupiter and the Earth. The region in the corona from 1 to 50 solar radii is particularly difficult to reach by opti- cal observations or space probes. Radio Missions Rockets. High apogee (1000 km) experiments; e.g., absolute calibration, 1-5, 5-10 MHz, 100-150 lb. [237] Explorers.—RAE-C ionospheric focusing and magnetospheric noise; RAE D&E: two or more element interferometer-supersynthesis test, location experiments; RAE-F: cosmic radio noise background; RAE-G: solar-system radio monitor. Orbiting radio observatory.-Ten-km filled-aperture antenna, circular polar synchronous orbit-2000-4000 lb. Solar Highlights Improved angular resolution XUV spectra and spectroheliograms may lead to under- standing the mechanism of nonthermal energy production-plasma and magnetic-field interactions; steep density, temperature gradients; shock and magnetohydrodynamic waves; particle transmission and ejection (perhaps the cosmic accelerator); a flow of ener- gy that controls the state of interplanetary space and planetary ionospheres. Absolute photometry of XUV resonance lines of atoms and ions will lead to improved abundance determinations and perhaps settle the question of different abundances at dif- ferent levels in the solar atmosphere. Absolute photometry of the UV continuum will provide direct observation of the tem- perature inversion.

EXPLORING THE UNKNOWN 613 White-light coronagraphs may reveal outward-moving disturbances from flares and other active regions. Visible spectrum observations with very high angular resolution exceeding that possi- ble from below the atmosphere will reveal details of sunspots, flares, prominences, plages, spicules, and the fine network structure. Solar Missions OSO-1: K coronagraph; OSO-J: spectrograph-absolute photometry 300-3000 Å; OSO- L: spectrograph absolute photometry _ < 30 Å; OSO-M: scanning spectroheliograph _ < 300 Å; OSO-N: K coronagraph; OSO-O: scanning spectroheliograph 300-1300 Å; OSO-P: spectrograph line profiles 300-1600 Å; OSO-Q: spectrograph line profiles _ < 300 Å. 5-Arcsec Spacecraft-ATM-A: [238] 1. Scanning spectrometer and spectroheliometer (300-1300 Å). 2. Slitless spectroheliograph, photographic (300-650 Å). 3. Spectrograph, photographic, high X/AX (900-4000 Å). 4. Small-field, large-scale X-ray telescope, and slitless spectroheliograph, photo- graphic (2-60 Å). 5. Large-field X-ray telescope with filters, photographic (2-60 Å). 6. White-light coronagraph, photographic. 5" Spacecraft No. 2: 1. High resolution (__ ~ 0.2") internally pointed telescope, with filters and spec- trograph (1100-30 000 A). 2. Spectrometer for line profiles and spectrum mapping (300-1000 Å). (This is probably a full load.) 5" Spacecraft No. 3: 1, 2. Spectrometers for X-ray spectrum mapping and absolute photometry (2-300 Å). (Probably at least two instruments.) 3, 4. X-ray line profile spectrometers to measure at least the strongest lines (2-300 Å). 5. X-ray imaging instrument (pinhole? Fourier shadowgraph? something else?) (A < 3 Å). Planetary Highlights Small pointed satellites will allow spatial scans of the planets in different spectral regions, which will allow us to deduce the vertical structure of hazy atmospheres (e.g., Venus, Jupiter). Ultraviolet photometry, as well as infrared observations from high-altitude aircraft, will provide critical knowledge of the planetary albedos, necessary to an understanding of the planetary heat budgets. A cloud model is fundamental to interpretation of spectroscopic measurements, which in turn can yield compositions, temperatures, and pressures. Measurements of the planetary hydrogen corona in Lyman-a radiation with high angular resolution (< 1 arcsec) can yield the escape temperature, an essential quantity to studies of evolution of the atmosphere and ionospheric structure. Essential features of a planet's meteorology could be obtained by long-period moni- toring of the atmospheric fine structure with large-aperture instruments in Earth orbit.

 Planetary Missions Rockets.■Survey spectrophotometry at several-Å resolution, 1800-3300 Å. Photometry in far-UV resonance lines, especially Lyman-a (1215 Å). Possibly high-resolution scans of narrow spectral regions of special interest. Explorers.-Extension of sounding rocket objectives but to fainter objects and improved spectral resolution, and with the important addition of spatial resolution over disk. OA O-A2 (WE P).-Broadband photometry, Lyman-a photometry; OAO-B: spec- trophotometry with 10 Å resolution; OAO-C: resolution of 0.1 and 0.4 Å over narrow spec- tral regions of special interest, possibly with spatial scans. Particles and Fields Highlights Observations within the solar system of magnetic fields and particles with energies from 0.5 keV to many GeV yield information on such diverse astrophysical problems as the 3° blackbody radiation, supernovae, the interstellar medium, the dynamical behavior of the galactic disk, nucleosynthesis and the origin of the elements, and stellar abundances— information not available through any other kind of observations or experiments. Cosmic-ray particle studies are related to radio, infrared, ultraviolet, X-ray, and g-ray astronomy measurements across the spectrum from the microwave background to mega- volt photons to form an overall picture which would be inaccessible from optical and radio studies alone. Through couplings between high- and low-energy processes such as the inverse Compton effect, all of the data related to a given object are related to each other and eventually all inputs are needed for a full understanding of the environment. High-energy astrophysics not only adds new windows to the cosmic electromagnetic spectrum by providing X-ray, g-ray, and particle and field astronomy, but also represents the first scientific unification of those disciplines and all other experimental studies of cos- mic processes. NEW DIRECTIONS FOR THE SPACE ASTRONOMY PROGRAM Comparisons with the current NASA space astronomy program reveal some of the new directions which will be required to implement [239] the AMB plan. Perhaps the most significant change is an increased effort in X-ray and gamma-ray astronomy. Less than 10 percent of the current NASA effort, X- and y-ray astronomy amounts to about a quarter of the AMB program, which assigns approximately equal levels of effort to optical, solar, and high-energy astronomy. The increase needed in the minimum bal- anced program is a major start in fiscal year 1971 on a new spacecraft with the point- ing, telemetry, and general sophistication of an Explorer-class spacecraft, but with a payload size capable of carrying large area X-ray detectors, spark chambers, and Cerenkov telescopes, as well as particle and field experiments in the 1- to 5-ton range. Also included is adaptation of a future OAO spacecraft or an equivalent vehicle to carry a state-of-the-art stellar X-ray imaging instrument comparable to existing solar instrumentation. Later, stellar imaging X-ray telescopes of about 1-m aperture, 10-m focal length will be required. The optical ultraviolet astronomy program has a mid-1970's goal of a 1- to 1.5-m tele- scope with diffraction-limited performance, as an essential intermediate scientific and

EXPLORING THE UNKNOWN 615 technological step toward the Large Space Telescope of the 1980's. This could be achieved either through a new spacecraft design or by upgrading an evolutionary OAO program. The infrared astronomy program has a most pressing need for research and develop- ment of detectors and small cooling systems which will permit infrared observations with the much greater efficiency that is commonplace at both shorter and longer wavelengths. Such advances could continue the present high rate of discovery of new classes of astro- physical phenomena from the ground and from airplane observatories. Observations of astrophysical objects in the longwave radio portion of the spectrum with the minimum angular resolution required to distinguish sources may require an antenna made of wires surrounding an area 10 km in diameter. However, a remote possi- bility of making similar observations by “supersynthesis” interferometric techniques must be studied before this large electronically filled aperture is initiated. The continuing need for observations of the solar surface with an effective angular resolution of 5 arcsec will require the development of a ground-controlled solar spacecraft with the instrumental sophistication of the ATM-A. Observations of the planets from Earth orbit will be accomplished with the instru- ments of the planned OAO's and a Small Astronomical Satellite optimized for planetary observations. [240] The acquisition of data on cosmic-ray particles and fields in the interplanetary medi- um requires a careful programing [sic] of small fractions of the missions to the planets, and the joint use of the “heavy Explorer” spacecraft for high-energy astronomy. An important element in the balanced acquisition of essential astrophysical data in the AMB plan is the continuing requirement for the smaller space experiments: the air- craft, balloons, rockets, and small Explorer-class satellites. Though less dramatic and unimposing by their nature, they have a great potential for economic and timely mea- surements of important data that can complement the other space-based and ground-based multiwavelength observations. An essential part of the AMB exercise to project the level of space astronomical research as far as possible into the future was an assessment of the availability and enthu- siastic interest of excellent people-scientists and supporting specialists, including several engineering and technical groups skilled in the measurement of astronomical radiation. Continuity, breadth, and active competition for flight opportunities must be maintained by a strong NASA program in Supporting Research and Technology (SR&T). Both SR&T and NASA's Advanced Research and Technology program must press for- ward to develop essential instrumentation such as lightweight optical mirrors, improved X-ray reflectors and detectors, X-ray photometric standards, electronic imaging systems, improved grating technology, infrared sensors and small cryogenic systems, devices which will be useful in ground based observatories of the future as well as space experiments. Support is also essential for the experimental and theoretical research in related areas of atomic and nuclear physics that will insure progress in analyzing the new observations resulting from these technological advances. In a properly integrated program of federally supported astronomy, NASA should have a responsibility to support particular ground-based instruments, especially those which are most closely and directly related to NASA's mission. Specific instruments, which are of comparable expense to some spacecraft and might be defended as separate line

616 NASA AND PLANETARY EXPLORATION items in the NASA budget, should include special-purpose monitoring telescopes of intermediate (60- to 100-inch) aperture, large optical telescopes in both hemispheres, and a large steerable paraboloid radio telescope. Document III-16 Document title: NASA Experiment Proposal for Manned Space Flight, Lunar-Surface Ultraviolet Camera, April 1970. Source: George Carruthers, personal collection, reprinted with permission. After initial test flights to the Moon, NASA attempted to maximize the scientific returns of the remain-der of the Apollo lunar landing program, when possible inviting scientists to propose experiments to be conducted in the lunar environs. The Naval Research Laboratory (NRL) was successful in receiv-ing NASA approval to fly an astronomy mission to the Moon's surface on the Apollo 16 mission, launched in April 1972. This is an excerpt from the NRL's proposal: a far-ultraviolet camera and spectrograph to be placed on the lunar surface. Under Principal Investigator George Carruthers, an NRL astronomer, the instrument recorded the spectra of many hot stars. [cover sheet] TITLE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION EXPERIMENT PROPOSAL FOR MANNED SPACE FLIGHT LUNAR-SURFACE ULTRAVIOLET CAMERA EXPERIMENT NUMBER (A combination of MSC Proposal "Lyman-alpha Ultraviolet Camera," 27 Aug 1969 with NRL Proposal P-11-69 “Far-ultraviolet spectroscopy of Diffuse Background Radiation, Diffuse Nebulae, and Stars, from the Lunar Surface" by George R. Carruthers and Herbert Friedman, dated 14 October 1969.) PRINCIPAL INVESTIGATOR (Signature) Thornton L. Page (Date) PRINCIPAL ADMINISTRATOR (Signature) Anthony J. Calio (Date) ********

EXPLORING THE UNKNOWN 617 [9] SECTION II. TECHNICAL INFORMATION 1. Objectives: From the lunar surface, outside the Geocorona, to obtain: a. Imagery in the band 1050 - 1230A (mostly Lyman-alpha 1216A) by differencing unfiltered (1050-1600A) and filtered (1230-1600A) photographs, all exposures accurately timed, of: (1) The Geocorona and Earth's Atmosphere, half sunlit (2) Possible clouds of Solar Wind and sky background near the band of the Zodiac at 45° and 135° from the sun, and changes after 5 or 10 hr. (3) Milky-Way star clouds, preferably in Sagittarius (4) Two or three nearby Galaxies, preferably M31, M32, and M33 (5) One or two Clusters of Galaxies, preferably the Coma Cluster b. Spectra in the range 300 to 1600A of: C. (1) Quasars and Seyfert-type galaxies (2) Small, bright galactic nebulae and stars (3) Interstellar extended HII regions (4) Interplanetary gas, zodiacal light, and solar wind near ecliptic (5) Background sky light in Coma Cluster and near pole of ecliptic A valid operational test of optical instruments in the lunar environment. 2. Significance The electronographic Schmidt camera will detect extended surface brightness as small as 0.3 Rayleighs (0.004 erg/sec.m^2 sterad at Lyman alpha). Although absorption in the line of sight will complicate imagery and spectra of distant sources, the Lyman-alpha resonance line of hydrogen is an extremely sensitive detector of hydrogen, the most abundant element in the universe. Lyman-alpha emission or absorption indicates the presence of hydrogen gas clouds, and the ratio of its intensity to that of Balmer-alpha 6563A, and of the 21-cm emission line, is related to the density and electron temperature. In normal stellar spectra, there will probably be Lyman-alpha absorption, partly due to cold interstellar hydrogen along the line of sight. Because of the Geocorona Lyman-alpha emission, observations from OAO and from other law Earth-orbiters are limited to relatively bright and compact objects. It is possible that the Solar-Wind clouds emit Lyman-alpha, and that other interplan- etary hydrogen will be detected near the plane of the ecliptic. Away from the ecliptic, interstellar hydrogen should be detected where it is excited by electron collisions or UV starlight. The spatial distribution of Lyman-alpha emission in the Milky-Way is thus relat- ed to the locations of interstellar gas and hot blue stars (Population I). [10] It is possible that very hot hydrogen exists in intergalactic space, and may be detect- ed between the galaxies in clusters. The sensitivity and wide angular field of the elec- tronographic Schmidt camera will show concentrations of intergalactic hydrogen if they exist in clusters, and may thus explain the “Mass discrepancy” in clusters of galaxies. Note that the Coma-Cluster redshift avoids the absorption of its Lyman-alpha in nearby inter- stellar clouds. Spectra will probably include absorption or emission lines at 1165A (CIII), 1206A (SiIII), 123-43A (NV), 1302-06A (OI), 1400A (SiIV) 1550A (CIV), 1610A (Fell), 1134A

618 NASA AND PLANETARY EXPLORATION (NI), 1200A (NI), and possibly lines of CI, CII, and as well as Lyman-alpha 1216A, and can eventually be used to determine chemical abundances in stellar atmospheres, nebulae, the interstellar medium, and the solar wind. Quantitative measurements in this wave- length range will therefore have significance in studies of all these objects, as well as Seyfert-type galaxies and quasars. A slat collimator provides spectra of background light with 30A resolution; with the LiF corrector plate removed from the camera, these should show Lyman-beta (1026A), HeI (584A) and HeII (340A). The latter two, and Lyman-alpha are strongly absorbed by the interstellar medium, but should appear in spectra of the Solar Wind. The operation of a camera-spectrograph on the lunar surface is the first step in tests of how effective an astronomical instrument may be on the lunar surface. This manned operation for 20 or 30 hours should be followed by use of a larger, remote-controlled tele- scope for geophysical and astrophysical purposes for a year or more. If the geo-astrolunar telescope (GALT) proves effective, a larger telescope may be appropriate at a lunar base. 3. Disciplinary Relationship The Geocorona and Lyman-alpha background are related to a decade of research on the Earth's magnetosphere and the Solar Wind, most of it done under NASA auspices. The most recent data were obtained by WEP and Celescope on OAO-A2. The Lyman-alpha emission from nearby galaxies is related to WEP measures from OAO-A2 of far-UV spectra described by Code (1969), and to 21-cm radio measures such as those reported by M. S. Roberts (1967). In connection with the mass discrepancy in clusters of galaxies, there has been speculation by several astrophysicists such as Rood (1969) about intergalactic hydrogen. In each of these areas, there is indirect evidence, but no direct confirmation of the amount and excitation of hydrogen. (It should be noted that Lyman-alpha imagery will provide dramatic photographs of the Earth's environment, and of distant regions of the universe. These are bound to stim- ulate public interest in the geophysics and astrophysics that can be done from the lunar surface.) Two measurements of Lyman-alpha sky background have been made at large dis- tances from the Earth; one by Barth (196) from MARINER V, and one by Kurt and Syunyaev (196) from the Soviet VENURA space probe. Both showed a concentration toward the galactic plane, which indicates that nearby interstellar [11] clouds are not com- pletely black in Lyman-alpha. In fact, Barth found particularly strong emission from the region of the Gum Nebula (RA 8hr. 2 min., dec.-39°55'). Far-UV stellar spectra obtained by Bless and Code (196) from OAO-A2, and by Carruthers (196) from Aerobee Rocket flights, seem to show ten times less Lyman-alpha than predicted from 21-cm radio mea- surements. Kurt and Syunyaev consider that the Solar-Wind protons interact with the mag- netic field of the Galaxy to produce a ring of recombining hydrogen in the plane of the Galaxy far from the sun. The observations proposed here will help sort out Lyman-alpha emission from these several sources, and will determine the changing ionization of the Solar Wind at different distances from the sun. 4. Experiment Approach (See Summary, page 1.) [not included]

EXPLORING THE UNKNOWN 619 A small electronographic Schmidt camera, shown in Figures 1 and 2 [not included], has been designed and built at the Naval Research Laboratory, and similar units have been flown by Carruthers on three Aerobee Rocket flights. Light is focused by the Schmidt cam- era with LiF correcting plate onto a curved KBr photocathode shaped to fit the focal sur- face. This photocathode, and its opaque backing, are kept at about 20 kV negative with respect to the film cassette, mirror, and rest of the instrument (which is at ground poten- tial, and completely shields the high voltage from the astronaut observer). A lontirudinal magnetic field is provided by bar magnets in the cylinder surrounding the camera, so that the photoelectrons are accurately focused on the film in the cassette (NTB-3 nuclear-track emulsion). This results in a detection efficiency about 20 times higher than the best UV- sensitive photographic emulsions (such as Eastman SC-5). The field of the camera is a 20°-diameter circle; a 27-mm circle on the film at scale 45 arc-min/mm. For direct photography, resolution will be 2 arc-min or better, and the den- sity of the developed film is accurately proportional to the integrated photon flux over a wide range of densities. A sunshade is desirable, even though the camera is to be deployed in the shade of the Apollo LM, to reduce scattered light from the nearby sunlit surface of the moon. A CaF2 filter (or separate corrector plate) is provided to cut out the wavelength band 1050-1230A. The KBr photocathode is sensitive to the band 1050-1600A, and two photographs must be taken to obtain a Lyman-alpha image. Spectra are to be obtained by placing a plane (reflecting) grating in front of the camera as shown in Figure 2. Using a 1200-line/mm replica blazed for 1300A first order, a field of stars or other small sources will produce spectra displaced about 10° from the zero-order (specularly reflected) positions on the focal surface. The film will then record spectra with fairly high efficiency over most of the 20° circular field, cen- tered exactly 90° off the camera axis by proper adjustment of the 3 x 4.3-inch grating. The dispersion is about 75 A/mm and resolution in stellar spectra about 2A. For extended nebulae and sky background, a “venetian-blind" (slat) collimator is [12] nec- essary to provide spectral resolution. Slats about 40 mm wide at 0.2 mm spacing along the grating dispersion limit the field to 20°x 0°.25 and provide spectral resolution of 30A. The camera must be pointed so that this narrow field crosses the target nebula (usually 2° or more in extent), and stars that happen to be in the field are easily dis- tinguished from the nebular spectrum by the limited width of their spectra. The 30-A resolution is adequate for nebulae and background since their spectra are expected to consist of widely spaced emission lines. The lower spectral resolution, set by the slat collimator, makes it unnecessary to have a corrector plate. If this is removed, spectra will extend down to 300A in the extreme UV. We therefore propose to modify the present NRL design to allow 3 choices for cor- rector plate (CaF2 or LiF, or none) and 3 choices for the front end (straight-ahead view through a sunshade, 90° reflection off the grating without collimator, and 90° reflection off the grating with slat collimator). The first selection can best be made by rotating a 6.5-inch wheel with two corrector plates and an empty 3-inch hole in it. The second selec- tion can be made by sliding the sunshade-grating assembly fully up or fully down, and by folding the slat collimator in or out, as shown in Figure 4. Because the astronauts will have difficulty seeing stars through their space suit visors, 620 NASA AND PLANETARY EXPLORATION it is necessary to point the camera by means of setting circles, one in declination (N-S) and one in hour angle (E-W). For objectives a(1-5) and most of b(1-2), pointing accuracy of 5° to 10° is adequate, since the camera field is 20°. For the background-light spectra, objectives b(4-5), the slat collimator requires pointing accuracy of 3° to 5°. A few of the targets for objectives b(1-3) are of about 1° extent in the sky, and the E-W strip field about 0°.5 wide must be pointed within 0°.5 in declination to get their spectra. Moreover, the faint objects require long exposures (up to 4 hours) during which the camera must be turned ("driven") westward at 0°.5 per hour. Hence a drive motor is required on the polar axis shown in Figure 3, and the axis must be parallel to the Moon's axis within 7°. The Moon's axis is inclined to the horizontal by an angle equal to the latitude of the landing site, and the polar axis is so inclined to the “table” in Figure 3. This “table" is to be sup- ported by a tripod that can be levelled using screws on the feet, which may be 10-inch threaded spikes tapped firmly into the soil. After levelling the table, the camera mounting must be rotated until the polar axis points north. This can most easily be accomplished relative to the sun line at the landing site. Because the camera will be set up in the shade of the LM, the second astronaut can walk down-sun out of the IM shadow about 100 feet, where he holds a staff or other tool at arm's length toward the sun with its shadow on his space suit. The first astronaut sets the camera circles at two predetermined settings (both about 90°) and adjusts the mount- ing so that the sighting bar on top of the camera points at the second astronaut's staff when the shadow is directly behind the staff. He then tightens the two lever-screws. fas- tening the mounting to the table with its polar axis within 1° or 2° of the correct direction north. A check on [13] the circle readings is then desirable. They can be set to predeter- mined settings (about 0° on each) to point the camera toward the Earth. A small mirror at the lower end of the almost vertical sighting bar will, show whether the camera is cen- tered on the 2° Earth. If necessary, the settings should be adjusted to center the earth, and the differences in circle settings should be added or subtracted from all later settings in the program of camera targets. After turning on the power supply (from a 28-volt 2-amp-hour battery pack in the cam- era mount, the astronaut selects the proper corrector plate and front end by gently tap- ping lever switches to operate solenoids. He sets the circle settings to predetermined settings and initiates a series of three to six exposures on each target. Care must be taken not to jar the camera tripod. Each exposure sequence starts with moving a new frame of film into position, exposing it 15 seconds, then moving another frame in for a 1-minute exposure, then 4-, 16-, 64-, and 256-minute exposures. After the 4-min. exposure is com- pleted, a small blue light is switched on, after the 16-minute exposure a green light, after the 64-minute one a white light, and after the 256-minute exposure no film transport takes place, and a red light is switched on. Depending on the expected faintness of the target, 3, 4, 5, or 6 exposures will be taken. Then a new corrector plate will be selected by the astronaut, possibly a new front end, and new circle settings. Then he initiates a new expo- sure sequence (which overrides any exposure in process). The three or more exposures ensure the maximum amount of information from each target, since each part of the image or spectrum will reach a density on one of the expo- sures which is on the linear part of the characteristic curve of photographic film. In gen- eral the imagery exposures can be short (0.25, 1, 4, and 16 minutes), while some of the

EXPLORING THE UNKNOWN 621 spectroscopic targets will require long exposures. The program of targets will be planned to fit in with other astronaut activities; it is desirable that the camera be deployed, adjust- ed, and started exposing early in the first EPA. A long exposure should be started at the end of the first EPA since it can continue for 5 hours while the astronauts are resting. Before boarding the LM for the ascent stage, the astronaut must remove the film cas- sette from the camera-spectrograph and carry it aboard for careful stowage (probably in a sealed can) during the return to MSC Houston. The only difficulty anticipated in the procedure outlined above is the astronaut's accurate sighting along the sighting bar attached to the camera. This bar will be designed and tested with astronaut help at MSC. If the desired accuracy cannot be achieved, one or two of the nebular spectra must be omitted. Of course, the astronaut is essential to accomplishing this experiment-in deploying the camera-spectrograph on its tripod, in pointing it with the aid of the setting-circles, in starting the exposure sequence, and in recovering the film for return to MSC Houston. [14] [15] 5. Baseline or Control Data: CÂMERA $1, direct imaging Kär photocathode, 1050-1550A Al + LAF on prinszy mirror #2 CANELA 12, spectra of small objects CSI photocathode, 1050-210OGA. Al + LiF on grating and adrezor #3 I CAMERA +3, spectra of diffuse background photocathode, 300-1550& To corrector plata Pt coating on grating and mirror Slat collinator (HH-13 film and automated film transport in all ommeras) Figure 5. Camaras for Aeroben-150 Trial Flight

 It would be desirable, though not required, to have simultaneous observations of the Geocorona (inside view) and Solar Wind made from OAO or OGO. The best landing site will be near the lunar equator at the time of first-quarter moon. The best time of year for observing the Coma Cluster and pole of the Galaxy is between April and July. In order to get Solar Wind near time of maximum solar activity, it is desirable to fly this experiment soon (1971). It would be highly desirable to fly three of the cameras with different corrector plates and front ends (as shown in Figure 5) on an Aerobee 150 rocket before the Apollo flight. The purpose of this test flight is not to test instrumental design (which will be fixed by astronaut handling of mockups at MSC) but to check exposure times on various targets, and to learn which classes of targets are most interesting in their far UV spectra. A good test field would be the Constelletion [sic] Orion which has a wide variety of early-type stars, a compact emission nebula (the Orion Nebula), and two extended emission nebu- lae (Orionis and Hothead Nebula region). The Geocorona Lyman-alpha emission would provide widespread foreground. The NRL can arrange this flight if it is approved, by early 1971 when Orion is visible from the dark site of the Earth. Of course, the data obtained from this first flight would be of scientific value in themselves. Document III-17 Document title: John E. Naugle, Associate Administrator for Space Science and Applications to NASA Administrator, Memorandum and Post Launch Mission Operation Report, May 17, 1971. Source: NASA Historical Reference Collection, History Office, NASA Headquarters, Washington, D.C. Seven years after the team from American Science and Engineering proposed to NASA a long-range plan for the study of x-ray astronomy from space (Document III-8), NASA launched the first satellite dedicated to x-ray astronomy. One of the space agency's many scientific Explorer satellites and the first of its Small Astronomy Satellites, the spacecraft was renamed Uhuru, the Swahili word for “freedom," because it was launched off the coast of Kenya on that country's Independence Day. Uhuru was a pio- neering force in x-ray astronomy, helping astronomers to identify and catalog more than 160 x-ray sources within and beyond our galaxy.

[no page number] EXPLORING THE UNKNOWN 623 Post Launch Mission Operation Report No. S-878-70-01 17 May 1971 MEMORANDUM S/Associate Administrator for To: A/Administrator From: Space Science and Applications Subject: Explorer 42 (Small Astronomy Satellite) Post Launch Report #2 Explorer 42 has been adjudged a success, based upon the results of the mission with respect to the approved prelaunch objectives. As of 12 April 1971, 4 months after launch on 12 December 1970, the SAS-A has com- pleted a full systematic scanning of the galactic plane and a substantially complete scan (95 percent) of the entire celestial sphere. The satellite remains operative with data being acquired in real time at a number of ground stations located around the earth on or near the equator. This planned backup real time mode of operation was initiated after failure of the tape recorder. It permits 60 percent acquisition of each full orbit of data to be obtained and allowed us to achieve the mission objectives. Experiment instrumentation continues to function in an outstanding manner, exceeding many design objectives. The spacecraft control section performance, with the exception of the tape recorder and some decrease in telemetry modulation which has not affected data quality, is excellent. To date, the acquired scientific data has touched on every aspect of observational X-ray astronomy. In addition to the expectation that many more X-ray sources would be discovered, significant unexpected phenomena have also been observed. In particular, the discovery of three new X-ray pulsars, identified as Cygnus X-1, Centaurus X-3, and Lupus X-1, has revealed a completely different class of pulsating X-ray source which differs in many respects from the previously known X-ray pulsar in the Crab nebula. The Centaurus source exhibits an even more startling characteristic in that its pulsation frequency appears to be extremely variable while all known pulsars, optical, radio, or X-ray exhibit no more than a slight variability while consistantly [sic] showing decreases in frequency over time. Some of the initial results have already been submitted to the Astrophysical Journal (letters) and presented to the American Astronomical Society at the annual meeting in Baton Rouge, Louisiana, on 31 March 1971 by the Principal Investigator, Dr. Riccardo Giacconi of American Science and Engineering, Incorporated. The results with emphasis on the Centaurus pulsar has also been presented to the annual meeting of the American Physical Society in Washington, D.C. on 27-30 April 1971. [no page number] The significant results already achieved have been derived solely from quick look data which is only a small fraction of the total amount of data actually acquired. It is expected that the analysis of the production tapes will develop and expand the catalog of known X-ray sources by many more sources than the 20 or so discovered to date. Based upon the results so far, it is probable that further surprises in X-ray source characteristics will appear in the data already acquired and throughout the continued lifetime of the satellite.

624 NASA AND PLANETARY EXPLORATION Dr. Giacconi, in a letter to the Director of Physics and Astronomy Programs discussing experiment performance and scientific results, stated his belief that Explorer 42 “has given us an unqualified scientific success and it has fulfilled and surpassed every expecta- tion we had before launch." [signature] John E. Naugle Document III-18 Document title: Memorandum to Director of Physics and Astronomy Programs, Office of Space Science, from Program Manager, Astronomical and Solar Observatories, Physics and Astronomy Programs, “Status of the Gravitational Physics Program,” April 12, 1972. Source: NASA Historical Reference Collection, History Office, NASA Headquarters, Washington, D.C. A space-based test of Einstein's theory of relativity intrigued NASA from its inception. With access to the reduced gravity environment of space, scientists might finally be able to test the validity of Einstein's prediction that the passage of time would slow down in a lower gravitational field relative to the passage of time on Earth. NASA's Office of Space Science held discussions with astronomers and clock manufacturers just months after the space agency opened regarding the feasibility of flying a clock aboard a satellite in Earth orbit to test the theory. By the early 1970s three space experiments designed to test relativity seemed possible. This memo describes the three experiments, called Gravity Probes, with which NASA became involved. While Gravity Probe A flew on a sounding rocket in 1976, Gravity Probe C, proposed by the European Space Research Organization, was ultimately can- celled. Gravity Probe B, designed to fly on a satellite, is still in development by NASA. [stamped] APR 12 1972 MEMORANDUM TO: FROM: SG/Director of Physics and Astronomy Programs Office of Space Science SG/Program Manager, Astronomical and Solar Observatories, Physics and Astronomy Programs SUBJECT: Status of the Gravitational Physics Program

EXPLORING THE UNKNOWN 625 NASA is actively engaged in three Gravitational Physics Projects: 1. GP-A, The Smithsonian Maser Clock Experiment 2. GP-B, The Stanford Gyroscope Relativity Experiment 3. GP-C, The ESRO Relativity Experiment These three experiments are described in the attached summary document for Gravity Probes that was prepared for “Proposed FY 73 New Starts" and the individual descriptions of the GP-A, GP-B, [a]nd GP-C Projects. The Gravitational Physics Program was reviewed by a Panel on 12 and 13 October 1971. The Smithsonian experiment was voted Category I unanimously and recommend- ed for flight with the highest priority. It was the consensus of the Panel that both the Stanford and the ESRO experiments were excellent to meet their scientific objectives, and that NASA should continue to support both groups to more clearly define the technical feasibility of the mission. The present status of the Projects is as follows: GP-A: The experiment was selected for flight in late 1971 by Dr. Naugle. The flight project has been approved and is now under active development by the Marshall Space Flight Center (MSFC). The planned launch date is early in 1975. [2] The only uncertainty at the present time, and this is minor, is whether the experiment instrument and the associated spacecraft subsystems can be constrained to about 150 pounds. This weight limitation is imposed by the ability of the Scout vehicle to fly a 10,000nm high trajectory. I expect an affirmative answer to the weight question by the end of April. There are no other problem areas of which I am aware. In fact, Smithsonian is very encouraged by a break through that permits the clock cavity to be cast rather than requir- ing lengthy machining. Further, the ERTS Project will loan MSFC an X-band transponder for initial tests, thus minimizing costs and compacting schedules. GP-B: As you are aware, Stanford has been supported with SRT funds for 8 to 10 years. During this time, they have determined the feasibility of using a highly precise gyroscope (accuracy of 0.001 arc seconds) to determine relativistic effects in low earth orbit (500 nm attitude inclined 90°); they have developed a ground-based dewar; and worked extensive- ly on the gyroscope and the spacecraft control system. In July 1972, BBRC was awarded a Mission Definition Study contract of four months duration. The study, which is now being reviewed at MSFC, indicates the feasibility of the GP-8 mission, provided that the following items are proven: gyroscope, dewar operation in zero gravity, dewar-gyroscope operation in zero gravity, and optical contacting for assembling the telescope and gyroscopes. The gyroscope is being developed at both Stanford (M-H contract) and MSFC. Recently, Stanford has demonstrated the levitation of the gyro rotor, and by June 1 expect that complete gyro operation in a 1-g field will be demonstrated at either or both Stanford and MSFC. A Cryogenic Workshop was held at MSFC in March to determine the state of the art in cryogenic systems at liquid helium and liquid hydrogen temperatures, and to attempt to permit a coordinated attack on the requirements of the planned and potential uses of cryogenic systems. I expect that recommendations resulting from the Workshop will be available in the next one to two months. This should provide a mechanism for developing a dewar for the Stanford experiment. [3] MSFC will take over the responsibility for the Stanford SRT effort in FY 1973. Present plans call for a $625K GP-B SRT budget at MSFC in FY 1973, of which $325 is earmarked for Stanford. The SRT support will continue until a flight project is approved in either FY 1974 or FY 1975. The earliest launch date would be the late 1970's. GP-C: ESRO has been constrained in their Solar Probe Experiment to funding for studies. In the past two years, they have studied the mission feasibility, the laser clock, the X- and S-band transponders, and a number of related items. Although they would like to do laboratory work on the drag-free system required by the experiment, no funding has been available. As you know, NASA is committed to aid ESRO in the Mission Definition. This com- mitment has resulted in reviews of the studies by MSFC, JPL, and Headquarters person- nel, and participation in their Mission Definition Group meetings in Europe. A year ago ESRO wanted NASA's cooperation for a Titan vehicle and in-orbit opera- tions support. Now, in addition, I understand they plan to discuss with Dr. Naugle on 18 April 1972 the possibility of further cooperation (maser clock, X- and S-band transpon- ders, and perhaps lasers). The additional support is brought about by the level of their scientific budget ($25 to 30M per year) and the present estimate of the GP-C mission of $50 to 100M which they probably cannot fund alone. They are also seeking cooperation from Germany with the use of the HELIOS spacecraft system. The future of this program is, in my mind, less firm than the GP-B mission, both from the technical and the funding standpoint. Technically, they will have to begin demon- strating the feasibility of systems, particularly the drag-free system, as we have done with the gyro experiment. In the funding area, they need help from outside ESRO. ESRO has been shooting for a luanch [sic] in the late 1970s. In summary, we are moving out with the GP-A mission. Both the GP-B and the GP-C missions are uncertain and do have technical areas that require feasibility demonstration. [4] You should also keep in mind that MSFC, under Dr. Decher, is undertaking a com- parative study to determine the relative merits of the various methods now being used or under consideration (ground-based efforts by MIT and JPL, GP-B, and GP-C) to deter- mine the relativity parameters ■ [Beta] and y [Gamma] and the solar quadruple moment J2. This study will probably not be completed for one year. It will involve all or the major- ity of the groups working in this area. C. Dixon Ashworth Enclosure [not included]

EXPLORING THE UNKNOWN 627 Document III-19 Document title: Space Shuttle Payload Planning Working Groups, Goddard Space Flight Center, Final Report, Volume 1: Astronomy, May 1973. Source: Nancy Grace Roman, personal collection, reprinted with permission. Document III-20 Document title: Interim Report of the Astronomy Spacelab Payload Study, Astronomy Spacelab Payloads Project, NASA, July 1975. Source: NASA Historical Reference Collection, History Office, NASA Headquarters, Washington, D.C. With President Nixon's January 1972 decision to pursue the development of the Space Shuttle as NASA's next centerpiece project after Apollo came the need to define the purposes it would serve. Like their counterparts focusing on other disciplines, the working group examining astronomical uses of the Shuttle determined that the new vehicle could serve a number of functions. Such purposes ranged from flying astronomical instruments for the duration of a Shuttle mission, to enabling astronauts to launch and service the Large (later Hubble) Space Telescope. The contribution to the Space Shuttle program by the European Space Research Organization (suc- ceeded by the European Space Agency in 1975) of Spacelab, a scientific facility that could be flown in the Shuttle's payload bay, provided yet another way in which astronomers could take advantage of the Shuttle. Many astronomers believed the frequency of Shuttle flights anticipated (two per month) com- bined with Spacelab's versatility would offer them a cost-effective and readily available means to fly their instruments in space. The 1975 report enumerates the astronomical uses and required subsys- tems for instrument integration identified by a NASA working group created to assess Spacelab's value to astronomy. Astronomers used the Spacelab facility on several occasions in the 1980s and 1990s with great success. [cover sheet] Document III-19 FINAL REPORT OF THE PAYLOAD PLANNING WORKING GROUPS Volume 1 Astronomy

628 NASA AND PLANETARY EXPLORATION MAY 1973 NATIONAL AERONAUTICS & SPACE ADMINISTRATION GODDARD SPACE FLIGHT CENTER Greenbelt, Maryland 20771 [xv] ASTRONOMY WORKING GROUP EXECUTIVE SUMMARY The principal advantages of space astronomy over ground-based observations reside in the greatly increased spectral coverage and angular resolution attainable from above the earth's atmosphere. For the first time celestial objects can be studied over virtually the entire electromagnetic spectrum from radio to gamma-ray frequen- cies. Even at the present early stage, this ability has produced a number of major sur- prises-for example, the overwhelming infrared emission from a variety of objects including planetary nebulae and galactic nuclei. Higher angular resolution will not only permit more detailed study of the structure of individual objects but, because of night sky suppression, will also allow observation of substantially fainter and hence more distant sources. By exploiting these advantages during the coming decades we will be able to solve, or at least to greatly increase, our understanding of such major sci- entific problems as the evolution of the early universe, the nature of quasars, galactic nuclei and radio sources, the formation of galaxies and of the stars within them, the origin of the chemical elements, and the origin of the solar system and of life itself. Solutions to these problems will impact all branches of human endeavor that have been seriously hampered in the past by the limited view of the universe available from the ground. The immense potential of space astronomy has been amply demonstrated during the last decade with comparatively small, exploratory instruments, limited to the observation of relatively bright sources. The time is now appropriate to establish in space the full range of observing facilities required to solve longstanding astronomical problems. The advent of the Space Shuttle renders this not only technically feasible but even moderately inex- pensive as compared to earlier ventures in space science. The cornerstone of our recommendations for the 1980s is the Large Space Telescope (LST), a three meter aperture, diffraction-limited telescope optimized for the ultraviolet and visible regions of the spectrum but usable also in the infrared. It will be operated as an automated satellite and will be periodically serviced by the Shuttle. The LST will extend significantly the distance to which we are able to probe the universe and offers, for example, a prospective solution to the cosmological problem, which has not proved pos- sible from the ground. A balanced program requires that this major instrument be sup- plemented by other more specialized instruments, as indeed are also required in ground-based observatories. [xvi] Because the LST is not planned primarily for the infrared, early emphasis in the Shuttle Sortie program is placed on this spectral region. Two infrared telescopes are pro- posed. A 1.5-meter aperture telescope, cryogenically cooled to about 20°K specifically for the 10-50 mm wavelength region.

 A very large uncooled telescope for the far-infrared and microwave region, and for planetary studies and narrow-band spectroscopy over the whole infrared range. Although both telescopes could operate as automated free-flyers based on the same spacecraft Support System Module (SSM) developed for the LST, both would gain by operation on the Shuttle. For the uncooled telescope the Shuttle allows the accommoda- tion of larger optics than would be possible with the Titan-compatible SSM, as well as the possibility of interchanging instruments at the focal plane during flight. The cryogenic sys- tem for the cooled telescope would be much simpler and less expensive on the Shuttle. These telescopes will be powerful tools in the exploration of such diverse phenomena as the immense infrared energy output of galactic nuclei, the conditions in the interstellar medium leading to star formation, and the physical properties and composition of plane- tary atmospheres and surfaces. In the ultraviolet, there is a definite need for a wide angle telescope to provide a UV survey in one broad wavelength band if the LST is to be used for many years to maximum effect. Subsequent use for studies at different wavelengths or for an ultraviolet spectral sur- vey would be valuable but less urgent. A one meter diffraction-limited telescope for the ultraviolet and visible will provide high angular resolution imaging over relatively wide fields of view (0.5°). Such a capability is required, for example, for photometric studies of stellar evolution in globular and open clusters and to supply observations of nearby galax- ies as the basis for LST studies of faint (> 21m) extragalactic sources. Unless or until the LST makes possible the frequent monitoring of solar system bodies, the 1-meter telescope can provide the needed synoptic coverage. The major advantage of the Shuttle for both these instruments is that it will allow use of photographic and electronographic detectors with their very large information storage capability. The 1-meter telescope will also provide an important test bed for auxiliary instrumentation for LST, allow specialized observations of a “one-of-a-kind” nature and relieve LST of observations of relatively bright sources. In addition to these five instruments, which the panel considered in detail, several other instruments which were considered briefly are typical of those which the Shuttle program should include. Examples are a very wide angle ultraviolet camera for the study of large scale, low surface brightness nebulae and star [xvii] clouds, a grazing incidence telescope for the extreme ultraviolet between the normal X-ray region and the Lyman limit of hydrogen, Explorer-class free flyers (to measure the cosmic microwave background for example), and rocket-class instruments which can fly fre- quently on a variety of missions. Except for the LST, each of the major astronomy instruments requires approximate- ly half of the space, weight, and other support of a Sortie flight. While each could be oper- ated remotely from the ground, our present impression is that in most cases it would be preferable to have the support of a four man Shuttle crew, in addition to the pilot and co- pilot, and a small laboratory to provide workspace, data storage, communications and access to the focal plane of at least one telescope. Although the individual instruments could share a Sortie mission with another discipline, compatibility requirements are severe. Astronomy requires stabilization of the Shuttle to near one arc minute (by means of control moment gyros), control of the pallet pointing direction throughout operation as dictated by the astronomical program, and a contamination-free environment. We therefore believe that we would be our own best companion. Most scientific direction must be from the ground, making it necessary to have excellent communication, includ- ing picture transmission, on both up and down links. A data relay satellite would be very helpful, although astronomy can use the intermittent communication provided by a ground network of tracking stations if adequate capacity compensates for limited time and if real-time communications are possible from the receiving station to a central control station at the same rate. Document III-20 [cover sheet] INTERIM REPORT OF THE ASTRONOMY SPACELAB PAYLOADS STUDY Executive Volume Prepared by the Astronomy Spacelab Payloads Project JULY 1975 NATIONAL AERONAUTICS & SPACE ADMINISTRATION GODDARD SPACE FLIGHT CENTER Greenbelt, Maryland ********** [51] CONCLUSIONS At this stage of the Astronomy Spacelab Payload Study, several conclusions about astronomical investigations and the effective methods of using the Spacelab for research in astronomy during the early 1980s have been identified. In each of the scientific areas of the study, solar physics, UV and optical astronomy, and high energy astronomy, a sub- stantial and valuable scientific program has been identified based on the experience of our past research in space, from recommendations from available studies and from con- sultations with scientists in the fields. The direct utilization of instruments operated from balloons, sounding rockets and satellites appears readily feasible and, in many cases, desir- able in the pallet mode of the Spacelab missions. Furthermore, the huge volume and weight available with the Space Shuttle affords the opportunity of incorporating large instruments and, in fact, facilities in the Spacelab program. The costs for the design and construction of such instruments for use with Spacelab appear very reasonable; signifi-

EXPLORING THE UNKNOWN 631 cantly less than instrument costs used in satellite payloads as the development of these instruments in many ways appears to parallel the techniques used with sounding rockets, balloons and aircraft. The methods of carrying out experiments with Spacelab are of a special nature with many similarities and disparities with the past techniques. Although the Spacelab missions represent full scale satellite-of-the-Earth operations, the missions are relatively shortlived, they may be amended by the crew of specialists on hand, and the return to Earth of the scientific equipment for maintenance and modifications is a guaranteed aspect of this mis- sion mode. In addition, the flight-into-orbit schedule is like the streetcar approach of the old Orbiting Geophysical Observatory, with an expected launching schedule of two space shuttles a month and probably about ten launches a year which may be available for some astronomical research. In effect, in about five years from now, the capacity for carrying instruments into Earth orbit will be increased by more than an order of magnitude and certainly more than the increase in the number of scientists, funds and other resources for carrying out research. It is essential that the methods for utilizing Spacelab match and adjust to such constraints. The Astronomy Spacelab Payloads Study has, from the engineering and mission analysis investigations, found several requirements to effectively use the Spacelab for astronomy. These requirements include a set of pointing platforms for a variety of instru- ments, special instrument containers for rapid and easy integration of scientific instru- ments, some standardization of power, telemetry and operational functions, and modular overall integration into pallets at the integration center for the scientific program. The conclusions so far derived from this study are listed below. They are divided into groups defined by scientific areas and by required subsystems to integrate the scientific instru- ments and by the cost of such integration and schedule procedures. [52] Scientific Program 1. Astronomers may have available simple and regular access to extended wave lengths into ultraviolet, superb image quality and a dark sky with a one meter class Spacelab UV Optical Telescope (SUOT). This ultraviolet facility can provide regular opportu- nities for a great number of astronomers, and with the wide field and regular access to focal plane instruments it would complement the Large Space Telescope. The SUOT should be developed for early Spacelab operation in 1981. 2. A solar telescope of large aperture for diffraction-limited observations extending over near UV and visible wavelengths can be of great value in studies of the heating of the solar chromosphere, for studying mass transport, magnetic field configurations, fine scale phenomena in sunspots and abundance distributions of elements in solar struc- ture. Such a spectroheliograph or One-Meter Telescope Facility should be developed for the 1980-1981 Spacelab program in solar physics. 3. A Solar EUV-XUV Soft X-ray Facility covering the solar spectral region from 2000Å to 2Å and a Hard X-ray Imaging Facility consisting of instruments to study X-ray, gamma ray and neutron emissions from the flaring and nonflaring sun, should be construct- ed for the early 1980 period of Spacelab operations. These facilities will be used for observations and studies of processes in the tenuous transition region and the coro- na, and studies of the physics of flares.

 4. The field of high energy astrophysics encompassing X-ray, gamma ray and cosmic ray astronomy includes an outstanding group of scientists with the developed technolo- gies, instrumentations and experiments that can fully utilize the expanded capability of the early Spacelab modes. One of the first Spacelab missions should be devoted to high energy astrophysics and regular opportunities for about two dedicated missions a year should be planned. 5. A wide variety of experiments derived from experiments using sounding rockets, balloons and satellites have been identified in each of the astronomy disciplines. Considerable flex- ibility exists in combining experiments and integrating instruments on pallets and seg- ments of pallets and these experiments are compatible with many Spacelab missions. An organized instrument preparation, integration and scheduling system for effectively and fully using each Spacelab mission would give scientists a powerful, productive and contin- uing means for carrying out research in astronomy and astrophysics. [53] Experiment Integration and Mission Management Operations 1. Three classes of pointing systems have been identified to fulfill the scientific require- ments for astronomical observation with Spacelab. (1) For facilities and large high energy instruments, the Instrument Pointing System (IPS) using an inside-outside gimbal, is under development by the European Space Agency. A pointing accuracy and stability in the one arc sec- ond range with limited roll is required for solar and astronomical observa- tions. For several of the X-ray experiments more modest, near one arc minute pointing, and instrument capacities of close to three tons are needed. Based on the preliminary projected scheduling of this pointing system for astrono- my and applications, a total of three (3) IPSs are required. (2) For pointing instruments of moderate weight a double-mount Small Instrument Pointing System (SIPS) has been under study. The SIPS can accommodate the moderate weight ATM class of solar instruments and the great majority of solar and astronomical instruments with a pointing accura- cy and stability approaching the one to two arc second range. Four SIPS units are required for astronomy. (3) A low-cost, one arc minute accuracy and 10 arc second stability system is need- ed for the many rocket-class instruments. This system may readily be devel- oped in-house by personnel of the Sounding Rocket Division of GSFC. Six of these units are needed. 2. Instrument canisters are required for thermal control and ease of integration of the wide variety of instruments considered for Spacelab astronomy flights. Canister con- figurations for compatibility with the SIPS and various instrument and mounting requirements can be developed. Contamination control is available with the instru- ment canister. The flexibility of the instrument canister is substantial, as it not only is used to control the environment of the instrument, but it also may afford a means of remote integration and becomes a shipping container for the instrument on Earth and in space. 3. Astronomical research with Spacelab involves mission planning and scheduling, instrument integration and mission operations, and requires Payload Operations

EXPLORING THE UNKNOWN 633 Control Center (POCC) at the GSFC. The experimenters would use the POCC dur- ing the installation and check out of instruments on pallets and later during the oper- ation of the instruments in orbit. The POCC would incorporate in-flight experiment operations, Spacelab communications, and data reduction operations. Investigator Stations would be incorporated into POCC for the operation and control of individ- ual and sets of experiments during the mission. [54] 4. For Spacelab mission planning, the assignment of prime mission goals to a partic- ular astronomical discipline, a “dedicated mission,” is scientifically and operationally efficient because the orbit, orientation, and mission sequences may be optimized. Solar physics, UV/optical astronomy and High Energy Astrophysics are generally mis- sion compatible and combinations of experiments in these fields also would be sci- entifically productive. The interrelationships among mission parameters are complex and necessitate iterative and continuing mission analyses studies and operations. The Astronomy Spacelab Payload Study has identified the mode for astronomical research using scientific facilities and instruments evolved through research using sound- ing rockets, balloons, aircraft, and satellites and the large instruments and instrument evo- lution making use of the Space Shuttle capacity and instrument return capability. The use of the pressurized module, the interface with free-flyers and space stations, and the gen- eral effects of working with the Spacelab mode requires further study. Of special concern is the ordering of the developments of facilities, the focal plain instruments and the sup- port for experiments for the early missions. Although the actual selection of experiments will be made from proposals submitted according to the NASA Announcements of Opportunity, early guidance in the relative value and comparison factors for the scientific and technological program is required. This is the initial year for Astronomy Spacelab Payload Study—in the next year the start and the ordering of the facilities will be made, the critical engineering subsystems for pointing, environment, power and data handling will be under development and the eval- uation of experiment proposals and the selection of early experiments will be initiated. The newly evolving capabilities of the Space Shuttle will not only permit a new approach to scientific investigations, but can influence lowering the costs of scientific instruments and their supporting subsystems. The availability of the shuttle as an Engineering test bed, the substantial payload carrying capacity, the presence of man in the operation and the capability to return the instruments should permit the development of ASP payloads in an evolutionary manner and enable the scientist and engineer to take risks. Cost savings should be expected. In addition the capability to refurbish and fly pay- loads should further increase the cost effectiveness of the ASP payloads. To take full advantage of this new potential, cost consciousness and constantly look [ing] for the “cost drivers" will continue to be a prime concern.

634 NASA AND PLANETARY EXPLORATION Document III-21 Document title: High Energy Astronomy Observatory Project Plan, NASA, June 13, 1973. Source: NASA Historical Reference Collection, History Office, NASA Headquarters, Washington, D.C. While ultraviolet astronomy dominated NASA's interest in the early days of the space program, the results of the gamma-ray and x-ray experiments carried aboard spacecraft during the 1960s and con- ducted from the ground expanded the popularity of high-energy wavelength studies among astronomers. Just as NASA had developed a program of large spacecraft, the Orbiting Astronomical Observatories, to explore the optical wavelengths, in the early 1970s the space agency initiated a series of multi-ton High Energy Astronomical Observatories (HEAOs) dedicated to gamma-ray and x-ray astronomy. After providing initial funding for the first two of three planned HEAOs in 1971, NASA suspended the program in early 1973 due to money shortages in the space program. This document portrays the state of the program as it underwent restructuring to accommodate the funding changes. In the end, NASA managed to fly three HEAO spacecraft, albeit less ambitious in scope than those originally planned; none of the HEAO missions planned for the Space Shuttle were flown. HMA- 1001 June 13, 1973 APPROVED: [signature] Rocco A. Petrone Revision C HMA-1001 HIGH ENERGY ASTRONOMY OBSERVATORY Director, Marshall Space Flight Center [iii] PROJECT PLAN APPROVED: [signature] J. Naugle Associate Administrator for Space Science FOREWORD This document is the agency plan for conducting the activities associated with NASA Flight Project 832, High Energy Astronomy Observatory (HEAO). This plan is prepared and maintained in accordance with NMI 7121. 1B, “Planning and Approval of Major Research and Development Projects,” (dated July 1, 1972), and the proposed draft of NMI 7120. 1A, “Authorization and Control of Space Science (OSS) Research and Development Projects." This document describes the overall plan and approach, and is the basic agreement between the Associate Administrator, Space Science, and the Director, Marshall Space

EXPLORING THE UNKNOWN 635 Flight Center for proceeding with the HEAO project. This plan is the basis for all project and lower level detail planning necessary for project operations, and is to be followed by all involved NASA organizations. It has been revised to reflect the agency decision to restructure the HEAO program to achieve most of the scientific objectives through a lower cost approach over a longer period of time. The restructured program consists of two groups of missions, designated Block I and Block II. Block I missions utilize conven- tional medium class launch vehicles while Block II concepts utilize Space Shuttle capabil- ities and approved experiments not assigned to Block I missions. Detailed planning as reflected herein addresses only Block I missions due to the preliminary nature of the sec- ond block. The planning will be further expanded at significant points in the life cycle to incorporate current project experience. This plan supersedes prior revisions in their entirety. The document is prepared and maintained for OSS by the MSFC HEAO Office in coordination with the OSS Program Office. The document will be updated when the degree of content change is sufficient to justify a new issuance. Proposed changes to this plan shall be submitted to the MSFC HEAO Office for coordination and staffing for management approval. [1-1] A. GENERAL ************* SECTION 1 - INTRODUCTION This document contains the overall plan for proceeding with the first group of mis- sions (Block I) established for the NASA project identified as: NASA Flight Project 832, entitled “High Energy Astronomy Observatory (HEAO).” The NASA code number is 85-850-832. B. PROJECT AUTHORIZATION The HEAO Project was initially established and authorized as one of the projects of the Physics and Astronomy Program by Project Approval Document (PAD) 71-85-001 dated July 2, 1971. The HEAO project was further delineated in Enclosure 6 of that FY 71 PAD. The PADS concerning the HEAO Project which had been issued as of the date of this plan are listed in Table 1-A in chronological order: TABLE 1-A CHRONOLOGY OF AUTHORIZATIONS 1. PAD 71-85-001, “FY 1971 Project Approval Document, Research and Development" and its Enclosure 6, both dated July 2, 1971. 2. PAD-85-850-P&A, “Project Approval Document, Research and Development," and its enclosure 6, both dated November 2, 1972. 3. PAD-85-850-P&A, “Project Approval Document, Research and Development," and its enclosure 6 both dated (TBD). ******** [1-3] C. PROJECT DESCRIPTION The Physics and Astronomy Program is primarily directed to extend the present knowledge of the earth's space environment, the sun, the stars, and the more distant celes-

636 NASA AND PLANETARY EXPLORATION tial bodies. This research is being conducted through a combination of various tasks such as Supporting Research and Technology and flight projects such as HEAO. The HEAO Project will search for and obtain high resolution data concerning high energy radiation from space (i.e., celestial X rays, gamma rays, and cosmic ray flux) by means of large unmanned earth orbiting observatories which will be built, launched, and operated as independent missions with complementary mission objec- tives and scientific experiments. The HEAO Project as presently contemplated is divided into groups of missions called “blocks." Block I observatories use the Atlas/Centaur as the launch vehicle. Block II would use the Space Shuttle capabilities with the observatories containing experiment hardware which could not be accom- modated in Block I. Block I consists of three missions, designated HEAO-A, HEAO-B and HEAO-C. The basic elements of Block I are shown in Figure 1-1 [no figures included]. HEAO-A is a scan- ning mission which will conduct a total sky survey for X-ray sources. HEAO-B is a pointing mission which logically continues the program by using an X-ray telescope to accurately locate, define, and determine the properties of the major X-ray sources.. HEAO-C is a scanning mission surveying the sky for gamma ray and cosmic ray. Figure 1-2 and 1-3 illus- trate the current observatory configurations for HEAO-A and HEAO-B. The HEAO-C configuration is being defined using candidate experiments to formulate the payload, hence an illustration is not shown. ******** [1-6] D. PROJECT STATUS The HEAO program as initially approved was suspended by an agency decision on January 5, 1973. The suspension is expected to remain in effect for approximately one year, during which time the previously planned program will be restructured and rebaselined as described herein. A recommended approach for restructuring the pro- gram was presented to the Associate Administrator for Space Science, on February 13, 1973, and then to the Administrator of NASA on February 20, 1973. Authorization to proceed with the redefinition and to establish firm cost and schedule plans was issued by the Office of Space Science (OSS) on March 5, 1973. OSS assigned experiments to missions HEAO-A and HEAO-B, and determined the candidate experiments to be con- sidered in defining the HEAO-C observatory. Redefinition of the selected Block I mis- sions has been initiated, and revised proposals are being prepared. Preliminary and conceptual design is underway. Definition of Block II payloads is proceeding at a low level of effort, pending clarification of the overall definition approach and development of funding plans. [2-1] A. GENERAL SECTION 2 - PROJECT PLAN SUMMARY This section summarizes the approaches and planning to be used in accomplishing the HEAO Block I missions. Each of the sections following this summary contains the detail necessary to provide a complete agency plan for the project.

EXPLORING THE UNKNOWN 637 B. PROJECT OBJECTIVES The objective of the HEAO program is to extend the present knowledge of celestial X-rays, gamma rays, and cosmic-ray flux through studies facilitated by means of large earth-orbiting observatories. The objective of the X-ray studies is to survey the entire sky for X-ray sources of about one-millionth of the intensity of the brightest known source, SCO X-1, and to investigate the shape and structure of these sources. Many sources show flares and flickering; the observatories will monitor these intensity variations. The initial survey mission will be fol- lowed by missions capable of performing studies on the spectra, structure, and location of these sources. The gamma-ray studies will be directed at the measurements of the gamma-ray flux and at determining source locations. Line spectra will be obtained and analyzed from the sources discovered. These studies, along with the X-ray studies, should contribute to our understanding of such phenomena as pulsars and quasars. The high energy particle experiments will examine the composition and synthesis of cosmic-ray nuclei. The isotopic composition of cosmic rays will provide information on the age and nuclear interactions producing the rays. The existence of very heavy nuclei will provide [2-2] an opportunity to probe into their origin, age and propagation through the interstellar medium. These studies will form the basis for future orbiting cosmic-ray laboratories, utilizing the capabilities afforded by the Space Shuttle. The objective will be achieved incrementally on an integrated basis by the HEAO mis- sions. Each mission is planned to achieve certain goals and to provide information which can be utilized in subsequent activities to achieve the project objectives. Section 3 [not included] describes the project and mission objectives in detail. Document III-22 Document title: J. Mather, Goddard Institute for Space Studies et al. "Cosmological Background Radiation Satellite," October 1974. Source: John Mather, Goddard Space Flight Center, NASA. One of the most important astrophysical measurements is that of the Cosmological Microwave Background (CMB), the remnant of the radiation resulting from the “big bang" at the origins of the universe. Because of the expansion of the universe in the 13-15 billion years since its origin, this orig- inally very hot radiation was thought to now be only a few degrees above absolute zero. The Cosmological Background Explorer (COBE), first proposed in 1974 and launched in 1989, gathered data of fundamental scientific importance on the CMB.

638 [cover sheet] [i] NASA AND PLANETARY EXPLORATION COSMOLOGICAL BACKGROUND RADIATION SATELLITE J. Mather P. Thaddeus Goddard Institute for Space Studies R. Weiss D. Muehlner Massachusetts Institute of Technology D. T. Wilkinson Princeton University M. G. Hauser R. F. Silverberg Goddard Space Flight Center OCTOBER 1974 COSMOLOGICAL BACKGROUND RADIATION SATELLITE INVESTIGATORS AND INSTITUTIONS John C. Mather 212-678-5609 Patrick Thaddeus 212-678-5621 Goddard Institute for Space Studies 2880 Broadway New York, New York 10025 Rainer Weiss 617-253-3527 Dirk Muehlner 617-253-4824 Massachusetts Institute of Technology 20F006 Cambridge, Massachusetts 02139 David T. Wilkinson 609-452-4406 Princeton University Department of Physics, Jadwin Hall Princeton, New Jersey 08540 Michael G. Hauser Robert F. Silverberg 301-982-2468 301-982-2468

EXPLORING THE UNKNOWN 639 Infrared Astronomy Research Program Laboratory for High Energy Astrophysics Goddard Space Flight Center Code 661 Greenbelt, Maryland 20771 [ii] TABLE OF CONTENTS

 [no pagination] A. Summary A group of four instruments to measure the cosmological background radiation is proposed for a Delta-class Explorer. The experiments address fundamental issues in obser- vational cosmology. Three of the experiments deal with the 2.7° K cosmic background radiation. The first is a definitive measurement of the spectrum of this radiation between 0.1 and 3 mm using Fourier transform spectrometry. The experiment will map the spec- trum at shorter wavelengths than have been possible from balloons and will measure the spectrum in the region around the blackbody peak with a precision of 10-4. It will also look for the emission from cold dust clouds and from infrared galaxies. The second and third experiments are devoted to measuring the large scale isotropy of the background radiation at a number of wavelengths to a precision of 10-5. It should be possible to mea- sure the motion of the Earth relative to the co-moving frame defined by the expansion of the Universe. Measurements at several wavelengths are required in order to distinguish anisotropy in the background radiation itself from anisotropy due to discrete sources. Definite observation of the Earth's motion relative to this radiation will be further confir- mation of the primeval fireball interpretation of the 2.7° K radiation. The fourth proposed experiment searches for diffuse radiation in the 5-30 micron wavelength range, expected to arise from interplanetary dust, interstellar dust, and, in particular, from the integrated luminosity of very early galaxies. The experiment is designed to separate these contributions by their spectral and directional properties. These four experiments have similar spacecraft requirements. Three require liquid helium, and two require slow rotation. The required scan of the sky can be provided by the orbital motion combined with precession of the orbital plane. The spacecraft could be shared with other experiments requiring near vertical pointing and the same simple scanning mode. The scientific importance of these experiments, their need for a space platform, and the relatively modest spacecraft requirements they impose all recommend this mission as an attractive first application of a liquid helium cryostat in space. B. Objectives and Significant Aspects An Explorer spacecraft equipped with cryogenically cooled instrumentation will pro- vide a uniquely sensitive system for study of diffuse cosmic radiation. It is proposed to develop a mission in which such a system is used to make definitive measurements on the radiative relics of the earliest stages of the universe. Four experiments are proposed, char- acterized by their common cosmological motivation and by compatible and relatively modest demands upon the spacecraft. The experiments proposed here include: 1. Spectrum of the 2.7 K Cosmic Background from 0.1 to 3 mm 2. Isotropy of the 2.7 K Cosmic Background between 0.5 and 3 mm Wavelength 3. Isotropy of the 2.7 K Cosmic Background at 3, 5, 9, and 16 mm Wavelength 4. Search for Diffuse Cosmic Radiation at 5-30 micron Wavelength. The personnel responsible for each experiment and principal requirements for each are summarized in Table 1. It should be noted that experiment (3) does not require cryo- genic cooling, but it is intimately related to the first two experiments, and does require a satellite platform for high quality results.

642 NASA AND PLANETARY EXPLORATION C. Plan of the Report In order to facilitate understanding of each experiment, the remainder of Section I discusses the objectives, concept, and spacecraft requirements for each experiment sepa- rately. It should be emphasized, however, that this separation is only for convenience: we strongly believe that this mission should be considered as a whole, since it represents a sci- entifically exciting and technologically modest first application of a cryogenic satellite. To this end, a technical plan providing for a suitable spacecraft and orbit for the complete mission is also presented in Section I. Management and cost plans for the mission are given in Section II. Appendix I contains a summary of the current status of cryostat devel- opment prepared by Ball Brothers Research Corporation. The operating principles of the Michelson interferometer used in experiment (1) are discussed in Appendix II. Biographies of the proposers are contained in Appendix III. Table 1 Title Description COSMOLOGICAL BACKGROUND RADIATION EXPERIMENTS Spectrum of the 2.7°K Cosmic Background from 0.1 to 3mm Wavelength Polarizing Michelson interferometer, 0.1 to 3 mm range, liquid helium cooled Isotropy of the 2.7°K Cosmic Background Wavelength Broad-band radiometer 3mm to 0.5mm, liquid helium cooled detector Isotropy of the 2.7°K Cosmic Background at 3, 5, 9, and 16mm Wavelength Microwave radiometers, 3, 5, 9, and 16mm Radiative cooling only Search for Diffuse Cosmic Radiation at 5-30µ Wavelength High sensitivity Spectrophotometry 5m-30m, liquid helium cooled Experimenters John Mather, *Institution P.I., GISS Rainer Weiss, P.I., MIT Patrick Thaddeus, Dirk Muehlner, Co-I, GISS Rainer Weiss, Co-I, MIT Dirk Muehlner, Co-I, MIT Michael Hauser, Co-I, GSFC Robert Silverberg, Co-I, GSFC Co-I, MIT David Wilkinson, P.I., Princeton Michael Hauser, GSFC Robert Silvery, CO-I, GSFC David Wilkinson, Co-I, Princeton John Mather, Co-I, GISS Instrument $500,000 - Cost 1,000,000 $100,000 - 150,000 $1,000,000 - 1,500,000 $500,000 - 1,000,000

Size EXPLORING THE UNKNOWN 643 30cm diam x 1m long inside cryostat which is 80 cm x 30cm x 60cm on outside of on outside of cryostat 3/4 of circumference, 30 cm thick 20 cm diam x 30cm long inside cryostat cryostat 1m diam x (1/4 of 1.5m long circumference) Mass 20 kg 20 kg 40 kg 20 kg Pointing near vertical, same, but spins about near near vertical, away from sun spinning about near vertical vertical axis away from sun at 1 rpm Telemetry 200 bits/sec 200 bits/sec 200 bits/sec 200 bits/sec Power 2W 5W 15W 2W Required Experiment Lifetime 6 months 1 year 1 year 1 year Document III-23 Document title: Nancy G. Roman, Program Scientist, and C. R. O'Dell, Project Scientist, to Members of the LST Operations and Management Working Group, with attached Minimum Performance Specifications of the LST, February 12, 1975. Source: Space Telescope History Project, National Air and Space Museum, Smithsonian Institution, Washington, D.C. Document III-24 Document title: George B. Field, Director, Center for Astrophysics, Harvard College Observatory, to Dr. James Fletcher, NASA Administrator, February 12, 1976. Source: NASA Historical Reference Collection, History Office, NASA Headquarters, Washington, D.C.

644 NASA AND PLANETARY EXPLORATION Document III-25 Document title: James C. Fletcher, NASA Administrator, to James L. Mitchell, Associate Director for Natural Resources, Energy and Science, Office of Management and Budget, April 12, 1976. Source: NASA Historical Reference Collection, History Office, NASA Headquarters, Washington, D.C. Before providing NASA with funds to plan for the Large Space Telescope (LST), the White House, as part of its pressure to reduce the NASA budget in the post-Apollo period, stipulated that the space agency had to find a way to reduce the telescope's cost from the price of $325 mil- lion that NASA was estimating in 1974. NASA thus undertook the task of developing an LST that would satisfy the financial concerns of the White House and Congress as well as the scien- tific objectives of the astronomy community. As even LST “father” Lyman Spitzer realized and advocated, reducing the size of the telescope's 3-meter primary mirror and thus scaling down the entire spacecraft represented one of the most obvious ways to cut the mission's costs. After review- ing the results of studies comparing telescopes with 3-meter, 2.4-meter, and 1.8-meter mirrors, the LST Science Working Group informed NASA that it would be unwilling to support a telescope with a mirror less than 2.4 meters in diameter. In this letter, LST Program Scientist Nancy Roman and LST Project Scientist C. R. O'Dell asked the working group whether they in fact drew the line at 2.4 meters or were willing to negotiate on this number with NASA Headquarters, which was inclined to pursue an even smaller telescope. Astronomers replied that a 2.4-meter mirror was their minimum. Among other factors, the strong opinions of these astronomers ensured that NASA indeed would proceed with a 2.4-meter LST. NASA was unsuccessful in convincing the White House to approve a new start for the LST in the FY 1977 budget, which President Ford transmitted to the Congress in February 1976. This was an outcome that was deeply disappointing to the leaders of the astronomical community, as suggested by the letter from Harvard astrophysicist George Field to NASA Administrator James Fletcher. NASA and the astronomy community redoubled their efforts to get an early start on LST approval and then have the project included in the FY 1978 budget. NASA requested such an approach in Fletcher's April 1976 letter to the Office of Management and Budget. The campaign in support of the LST was successful, and the budget sent to Congress by the outgoing Ford administration in January 1977 contained funds to begin project development. (The FY 1978 budget also contained a new start for another major science project, the Jupiter Orbiter-Probe mis- sion that became Galileo.)

EXPLORING THE UNKNOWN 645 Document III-23 [no page number] TO: Members of the LST Operations and Management Working Group Dear Colleague: February 12, 1975 We appear to be approaching a very pivotal time for LST. As you know, NASA will sub- mit its budget for FY77 (starts 1 October 1976) by May 15 of this year. If LST does not appear as a new start in this budget there is a very real risk of the program foundering. Should this occur, we expect that it might be several years before LST could be restarted and that precursor to LST missions might begin to dominate NASA planning. The issue that will ultimately decide the question is program cost, i.e., if NASA can afford it, we'll have an LST and starting in FY77. As you saw at the December Working Group meeting, the cost figures for all elements except the SSM are by now very well defined and the program is austere. Within a few weeks we will have the SSM contractor's estimates of their costs and the picture will be complete. The program that we are now costing is very significantly reduced from that which we started Phase B with in the summer of 1973. We have de facto reduced the aper- ture to 2.4-m, allowed the angular resolution to degrade, reduced the number of Scientific Instruments, etc. All of us were party to these decisions and we hope that you feel the Program Scientist and Project Scientist have not made these concessions without your full knowledge and consent. We were requested to prepare a document describing the "Minimum Performance Specifications for the LST", which was done in December. (The current version of this is enclosed herewith, slightly revised according to Al Schardt's insistence that the resolution number agreed to at the October meeting was 0.10" and the fact that a theoretically perfect system with a sec- ondary mirror observation of 32% will not give more than about 64% within the first dark ring.) [2] The question for us to address is “Do we defend this as the true minimum LST against efforts to bring the program down in cost by sacrificing performance?" We feel that the costs being identified are well studied and justified for this program and any significant cost savings would be at the expense of performance. Therefore, we are in a position of standing-by [sic] this definition of the minimum LST and running the risk of foundering or renegotiating the cost at a significant cost and performance reduction. Both of us feel that the program has already been so drastically reduced that we are at the point that the line must be drawn and that the agency must either allow us to move ahead with at least this minimum LST, or that we are confronted by an agency money problem and put LST into hold until the future. Although we feel that the derivation of the definition of a minimum LST was done by all of us, we feel that you should have the opportunity to individually and collectively state your opinion at this crucial time, as the risks are quite real. A further complication is the proposal by Al Schardt that we try to reduce program costs by constructing an evolving complexity LST, i.e., one that at initial launch would not meet the minimum performance specifications; but, one that would possess the potential for upgrading later upon successive ground returns to a full LST capability. Although detailed calculations have not been made, it appears that such a plan is plausible and at some reduction in cost to initial launch. The overall cost to eventually reach LST perfor- mance with this plan would certainly be higher than the direct approach. Although Dr. Schardt considers this plan very seriously, he will not support a plan that is not supported by you, the ultimate users and justifiers of LST. It now appears that a decision on FY77 may be made in March, before our next scheduled Working Group meeting. Therefore, we'd like to ask each of you to write us your opinion on "Do we bargain or do we draw the line?" by February 25. Please write to either of us with a copy to the other. We will then set up a telephone confer- ence to summarize the situation. Preferably this conference would be on the after- noon of March 4. Please let us know where you will be on that date, and what are "impossible" times for you. Nancy G. Roman Program Scientist C. R. O'Dell Project Scientist [no page number] [attachment] Revised 27 Dec 1974 Minimum Performance Specifications of the LST The performance specifications imposed by the scientific users of the LST define that set of conditions necessary to have broad scientific support, the ultimate justification for its construction. The present specifications for a minimum LST were prepared by the Project Scientist after consultation with the Program Scientist, the LST Operations and Management Working Group and many other individual astronomers. Individual opinions on specific points vary; however, the following does represent the composite view: 1. LST is a versatile, long life-time observatory; i.e., it must have the capability to accommodate a variety of scientific instruments and vary the complement of instruments with time. 2. The optical image should satisfy the following requirements in the visual and near-vacuum ultraviolet wavelengths: Resolution using the Rayleigh criterion of 0. 08 arc-seconds; A full width half intensity diameter of 0.08 arc-seconds; 80% of the total energy of a stellar image must be contained within a diameter of 0.15 arc- seconds. 3. The overall LST system must work efficiently down to wavelengths permitting the study of the Ly (alpha) line at 1216Å, requiring reaching to about 1150Å. Likewise, it must allow efficient observations at infrared wavelengths longer than those readily accessible from the ground. 4. The system should accommodate at least four scientific instruments. 5. It must be capable of measuring objects appreciably fainter than those accessible from the ground. At the present this means going to about magnitude 27 with a signal to noise ratio of 10 in 4 hours of observing time.

EXPLORING THE UNKNOWN 647 6. It must be capable of measuring extended sources of surface brightness 23.0 m/[illegible] with a signal to noise ratio of 10 in 15 hours. 7. The LST must have the capability of using Scientific Instrument entrance aper- tures comparable in size to the image. Document III-24 [no page number] Center for Astrophysics 60 Garden Street Cambridge, Massachusetts 02138 February 12, 1976 Dr. James Fletcher, Administrator Code A NASA Headquarters Washington, D.C. 20546 Dear Jim: Harvard College Observatory Smithsonian Astrophysical Observatory I am writing to you in my capacity as a member of the ST Working Group, not as Chairman of PSC, to share my thoughts with you on ST. I hope my comments will be help- ful; they are meant to be. As I am sure you have been, I was surprised by the depth and breadth of the reaction among astronomers to the decision not to have a 77 new start. I felt that the explanation you gave in the authorization hearings was intelligible; certainly the major budget cut thrust upon NASA at the last minute would have made it very difficult to get a new start for ST in 77. Why was the reaction so powerful, then? To me, it simply testifies to the very deep and widespread excitement ST has gen- erated in the astronomical community. I have watched the ST concept grow since I first heard about it from Lyman Spitzer in 1952. The response of the community, at first hesitant, has now reached the point of virtual unanimity among professional astronomers. The reason for this is that the ST, with its diffraction-limited images and its UV and IR capability, promises significant forward steps in virtually all branches of astronomy, and major steps forward in several of them. As a result, astronomers find, when they think about ST, that there are problems they are personally excited about which can be solved by it. Perhaps the ST is unique among space instruments in this respect. ST is not a specialized spacecraft of interest to only a small subdiscipline, but a true observatory with all the broad capabilities one finds at a facility such as Kitt Peak. Such national observatories on the ground are used by large numbers of astronomers for a great diversity of purposes, and for that reason, they enjoy strong nationwide support. The same is true of ST, but even more so because of its enormous capabilities. I dwell on the enthusiastic support among astronomers to help you understand the depth of feeling you are now [2] encountering. Astronomers who are normally quite restrained have become passionate because they feel so frustrated. In this con- nection, Jim, I was disappointed that you could not meet with the ST Working Group (although I understood why you could not), because that would have been a good opportunity to defuse their feelings and allay their fears. I feel particularly disap- pointed because strong statements of support like those you made in Williamsburg would have made it very apparent that you mean to start ST in 78. As things are now, there are serious doubts among the senior astronomers as to NASA's true intentions. I think you will candidly admit that even with the best of intentions, it will be very dif- ficult, in view of a possible change of administrations, and the usual problems with the budget, to get a new start in 78. The critical issue, as I see it, Jim (and here I speak completely frankly) is how to transform your statement in Congress into something tangible that will give us something to work with. I am concerned that if this is not done, there will be a really serious loss of morale among the top astronomers who are supporting the project - and I am sure that you are aware that Burbidge, Spitzer, and the others are at the absolute top of their profession. This would be a disaster which we must somehow avoid. If at all possible, Jim, I urge you to commit NASA to major activity for the ST in 77, if possible via a direct authorization by Congress. I want to speak to you candidly about the public attitude toward the ST. Certainly very few of even the educated public are aware of the ST program, and the scientific results that would flow from it. The astronomers, of whom I am one, must take major responsi- bility for not publicizing the concept even better than has been done. But I am absolute- ly sure that with the proper approach, we can tap the wonder of distant and beautiful things that ordinary people feel when given a chance. I would estimate that there are several million people in the U.S. who are fascinated by astronomy, cosmology, deep space, and the universe. Among them are many of our leaders, executives, and publicists. There is a great and enduring fascination with the depths of space and time out of which the earth, life, and finally humanity, arose. If we can show [3] how ST will probe the depths of space and time, we will have opened the door to public support. How can we do this, Jim? An increased program of public education is needed. There are many astronomers who will participate willingly in such work in the year ahead. I am going to try to contact leading publications to offer articles on space astronomy and the ST. Others have offered to do the same. Much can be done through the American Astronomical Society's Task Group on Education in Astronomy, to get materials into newspapers, classroom resource materials, and other educational literature. In all of this, we desperately need the assistance of NASA offices at all levels, includ- ing your own, the program offices, and the public information office. We need contacts with media people, we need guidance, and we need written and visual materials. For some reason, NASA has not been as effective in presenting its space astronomy program as it has its planetary exploration program, and NASA should strive for parity in this area. With

EXPLORING THE UNKNOWN 649 proper collaboration between NASA and the scientific community, we can get our mes- sage across. Most of all, Jim, we the astronomers need to meet with you face to face, so that you can allay the fears which cripple effective action, and so that your own interest and excite- ment about ST can be communicated to all. I suggest that you consider addressing a meet- ing of the American Astronomical Society, much as you do the societies associated with the national aerospace effort, for a frank discussion of your hopes for a meaningful space astronomy program. I would be happy to discuss these and any other step we can take toward the ST at any time. Sincerely, [signature] George B. Field Director Document III-25 [stamped] APR 12 1976 Mr. James L. Mitchell Associate Director for Natural Resources, Energy and Science Office of Management and Budget Washington, DC 20503 Dear Jim: Following up John Naugle's recent discussion with Hugh Loweth on the Space Telescope, I would like to summarize our current approach to this project. As I am sure you recognize, a new start for the Space Telescope will be a very high priority item in NASA's FY 1978 budget recommendation. The history of the Space Telescope extends back to studies and scientific discussions in the early 1960s; by 1965, there was a small but growing cadre of astronomers that rec- ognized the unique contributions to many disciplines that could flow from a large tele- scope operating at the diffraction limit above the interference of the atmosphere. With the advent of the shuttle in 1971, it became clear that some of the major prob- lems of maintaining an astronomical facility in space could now be overcome at reason- able costs, and more specific project planning began. The astronomical community eventually settled on a set of technical parameters for a large space telescope: to warrant the considerable investment required, the instrument should be some 10 times more pre- cise than any ground based telescope and should be able to resolve stars of at least the 27th magnitude. These requirements translated into an instrument with a 3-meter aperture operating at or near the diffraction [2] limit. Our early feasibility and design concept studies indicated that it was quite possible to build such a telescope, but that its costs would be high- er than either we or the scientific community felt desirable. We then began to examine alternate aperture sizes in relation to probable cost and to technical performance. We found that with an aperture of some 2.4 meters we could meet the scientific requirements and at the same time significantly reduce overall system development complexities and therefore cost. The astronomical community, after some initial concerns that were dissipated by thor- ough engineering analyses, enthusiastically accepted the revised specifications: a 2.4- meter, diffraction-limit aperture and a pointing accuracy of .1 arcsecond. In FY 1975 and 1976, therefore, we funded competitive industry studies for the Space Telescope with all elements designed to come together to support a new start in FY 1977. As it turned out, the Space Telescope was deferred for consideration until the FY 1978 Presidential decision cycle. It appears we had underestimated the commitment to the Space Telescope pro- ject that had grown over the years among scientists, industrial organizations, and members of Congress. We have been inundated with severe criticism from virtually every academic institution associated with astronomy. We have been urged forcefully by the aerospace and optical contractors to do something to alleviate the high costs of their holding together effective engineering teams in order to be able to bid on the telescope project if and when it were authorized and funded. (Here we are dealing with three aerospace firms in competition for the spacecraft and two or more optical houses competing for the telescope assembly; all were geared up to propose in FY 1977 and now are faced with the economics of retaining their technical teams for another year.) The House has chosen to authorize an FY 1977 new start on the Space Telescope at the level of $3 million and our [3] Subcommittee, supported by the urg- ing of the industrial and scientific community, has required us to provide them a plan that would permit early selection of the winning spacecraft and optical contractors (thereby relieving the losers of the considerable financial liability inherent in trying to retain a competitive posture well into next year). Our response to this request from Chairman Fuqua is due early this month. The Senate did not follow the House lead. The Senate bill does not authorize a new start for the telescope in FY 1977, but the report language accompanying the bill is very strong in urging NASA to proceed with the project as “the item of highest priority" in FY 1978 and requesting that NASA sustain the Space Telescope pre-contract activities to assure an orderly and efficient transition into development. The House-Senate conference to accommodate the differences between the two bills is expected to be completed by the Easter recess. We believe we can take certain actions now that would preserve the momentum of the program without committing the Administration and that would permit the House to recede gracefully over the question of the authorization for the Space Telescope. What we propose to do is the following: a. In August of this year, we would issue a formal Request for Proposal (RFP) for the telescope assembly; this RFP would clearly state that: no contract would ensue until and unless there were authorization, appropriation, and apportion- ment actions appropriately taken in the future. The responses to this RFP would

EXPLORING THE UNKNOWN 651 be available in mid-October which would help in the formulation of the President's FY 1978 budget. The NASA source evaluation process would proceed during the winter and be completed in the March-April period of 1977 -- well after the decisions on the President's [4] budget and even after the completion of the authorization and appropriation hearings. Depending on the situation at that time, we could then terminate the process (if the project were not approved) or proceed with detailed negotiations aimed at a contract effective on October 1, 1977. b. We would follow essentially the same pattern with the spacecraft RFP, except it would be released in October of 1976, responded to in December of 1976, and the responses evaluated by May or June of 1977. C. We would solicit Principal Investigator responses for the Space Telescope's scien- tific instrumentation beginning around September of this year and extending well into 1977 before any decision would be made. We feel that this limited action, not committing the Administration in advance of the normal budget process, will place us in a sound position to proceed with the pro- ject if it is approved during the coming cycle. Conversely, we feel that to take no steps until mid-1977 would result in serious program discontinuities and even some inequities-: — Some of the contractors have indicated that they might be unable to maintain their teams and competitive postures until mid-1977 and would therefore be unable to bid. All the contractors have indicated a strong desire for an early selection process even in the absence of funding. All the contractors have stated that their technical positions would have seriously eroded by mid-1977, leading to weaker technical proposals and greater cost uncertainties (some have said they would require an additional preliminary design phase, extending the program and increasing its costs). [5] The Congressional supporters of the Space Telescope might be moved to force unnecessary and undesirable confrontations with NASA and the Administration on the question of responsiveness to their guidance. - The scientific supporters of the Space Telescope would continue to exert what pressures they could for an overt action by the Congress and the Administration, perhaps thereby reducing some of the positive impact of the President's recent science and technology message. In summary, we feel that the most prudent course to take is to inform the interested communities on a low-key basis that we will proceed with an early selection process begin- ning in late summer. We believe that this approach will not commit the Administration in advance of the normal budget process, that it will retain the necessary flexibility on the part of the Government to adjust its plans to fit future situations as they become real, and that it will capitalize on current support for the Administration's posture on science and technology.

652 Sincerely, [Original signed by] James C. Fletcher Administrator bcc: A/Dr. Fletcher AD/Dr. Low AA/Dr. Naugle ADA/Gen. Crow B/Mr. Lilly X/Mr. Williamson SD/Dr. Calio AEM-3/Ms. LeCompte NASA AND PLANETARY EXPLORATION Document III-26 Document title: Smithsonian Institution Astrophysical Observatory, “Proposal to National Aeronautics and Space Administration for the Study of the 1.2 Meter X-ray Telescope National Space Observatory,” April 1976. Source: Harvey Tannenbaum, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts, reprinted with permission. By the mid-1970s, NASA had taken a strong interest in high-energy astronomy, as evidenced by the launch of Uhuru and the development of the High Energy Astronomy Observatories. Encouraged by NASA's commitment to studying high-energy wavelengths, astronomers at the Smithsonian Astrophysical Observatory presented to NASA in 1976 an unsolicited proposal for the development of a major space-based x-ray observatory. The proposed spacecraft would enable astronomers to see farther than ever before possible into a universe of exploding stars, colliding galaxies, and enigmatic black holes-phenomena evident only by the x-rays they emit. Embracing the idea of this mission, which became known as the Advanced X-ray Astrophysics Facility, NASA began conceptual studies and assembled a working group to define scientific objectives for the mission in 1977. The satellite was finally launched, and named Chandra, in 1995.