

NASA'S Initial Flight Missions in the Small Explorer Program

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The National Aeronautics and Space Administration (NASA) Office of Space Science and Applications has initiated a new component of the Explorer Program to provide research opportunities characterized by small, quick turn-around, and frequent space missions. The objective is to launch one to two payloads per year, depending on mission cost and availability of funds and launch vehicles. The first Small Explorer Announcement of Opportunity, released in May 1988, invited proposals in Astrophysics, Space Physics, and Upper Atmospheric Science disciplines. From the 51 proposals received, four missions were selected for flight. The initial flight missions described in this paper, in order of tentative launch date, are: the Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX); the Submillimeter Wave Astronomy Satellite (SWAS); the Fast Auroral Snapshot Explorer (FAST); and the Total Ozone Mapping Spectrometer (TOMS).

Future NASA plans for the Small Explorer program include issuing an Announcement of Opportunity every few years and selecting only the investigations that can be launched within a three year period. Some enhancement of launch vehicle capability and certain procedural changes for mission proposals are also anticipated.

SMALL EXPLORER PROGRAM CONCEPT

The National Aeronautics and Space Administration's (NASA) Explorer Program goes back to the very beginning of U.S. space exploration using artificial satellites. Since the launch of Explorer-1 in February 1958, the 71 Explorer missions launched through 1987 have provided many significant results and discoveries. Historically, the Explorer program has provided flight opportunities for scientific investigations from interplanetary space to low earth orbits. However, the new Small Explorer program will focus on low earth orbits serving the space science disciplines of astrophysics, space physics, and upper atmospheric science. This will help reverse the trend in recent years toward larger, more complex missions and dependence on the Space Shuttle for launches, which has resulted in reducing the opportunities for space science research both in number and frequency. Thus, the most exciting feature of the Small Explorer program is a return to more frequent, lower cost missions for better serving the scientific community.

The roots of the new Small Explorer program go back to a workshop sponsored by NASA's Astrophysics Division in February 1987, which brought together over 60 scientists from space physics and astronomy disciplines to assess the scientific potential of small, low cost payloads.¹ This workshop, held at Goddard Space Flight Center, produced a resounding endorsement of the program concept. The scientists actually identified about 40 potential small payloads which could produce valuable science within the defined constraints of orbit, weight, and probable cost. It was estimated that about 30 high quality proposals might be received in response to an Announcement of Opportunity for such a program.

The goal of the Small Explorer program is "to provide flight research opportunities to the space science community, which are characterized by small, quick turn-around, and frequent missions." The emphasis is on high quality scientific research with missions of modest scope and instrumentation sufficiently mature to be launched within three years of selection. For its part, NASA will seek to maintain a flight frequency of at least one mission per year and will select payloads which complement major space missions, prove new scientific concepts, or make significant contributions to space science in other ways. Each principal investigator will be responsible for carrying out his proposed investigation from start to finish. The program will also afford opportunities for international cooperation, either through traditional co-investigator roles or with joint missions, on a "no exchange of funds" basis.

ANNOUNCEMENT OF OPPORTUNITY PROCESS

The Small Explorer program is no longer just a concept; it is very much alive and moving toward its first flight mission. In consonance with the "quick turn-around" objective, NASA published the Announcement of Opportunity (A.O.) for this program and selected the first group of missions in less than eleven months. The A.O. for the Small-Class Explorer Mission (A.O. No. OSSA 2-88) was released on May 17, 1988. This A.O. provided an opportunity for proposing space science investigations on spacecraft launched by Scout-class launch vehicles. The anticipated high level of interest within the scientific community was verified when over 250 persons attended the Preproposal Conference held at Goddard Space Flight Center on June 21, 1988.² The following description of the proposal evaluation process will provide some idea of the thoroughness of the review subsequently received by all proposals.

Fifty-one Small Explorer Mission proposals were received by the required response date of September 30, 1988. These proposals were divided into seven discipline groups by the Program Scientist and NASA Science Discipline Chiefs, namely, High Energy Astrophysics, Visible/Ultraviolet/Gravity Astronomy, Infrared/Submillimeter/Radio Astronomy, Solar Physics, Cosmic and Heliospheric Physics, Space Plasma Physics, and Upper Atmospheric Science. Due to the large number of proposals received in the Space Plasma Physics discipline, this group was further subdivided into two review panels according to the type of investigations proposed, i.e., Particles and Fields, and Optical/Imagery. Some proposals were reviewed by more than one discipline panel.

During the first three months following receipt of the proposals, a technical assessment of all investigations was conducted by the NASA Goddard Space Flight Center Technical Evaluation Team. This process focussed on the technical feasibility of developing the proposed instrumentation, conformance to launch vehicle specifications and the NASA-developed spacecraft bus, the adequacy of the management plan, and the realism of the proposed cost. During the same period, Peer Review Panels were selected for the scientific evaluation, which was conducted during January 1989. This process involved eight discipline panels, consisting of 74 scientists, meeting concurrently at one location near Baltimore, Maryland.

The scientific review was based on the following evaluation criteria which were stated in the Announcement of Opportunity:

- The overall scientific merit of the proposed mission and its likely impact on space science.
- The overall technical merit of the proposed mission.
- The adequacy of the proposed investigation to fulfill the objectives of the mission.
- The degree to which the proposed mission complements other elements of NASA's program in the relevant discipline and serves to meet the overall scientific goals of that program.
- The adequacy and completeness of the data reduction and analysis plan.
- The capabilities and experience of the investigators.
- The experience, interest, and prior performance of the investigator's institution in providing the necessary support to insure that the proposed investigation can be completed satisfactorily.

The technical evaluation was based on:

- The compatibility of the investigation/mission with the Scout-class vehicle capability and NASA's available mission support capability.
- The compatibility of the proposed instrumentation with the proposed spacecraft hardware.
- Current state of development of the proposed instrumentation and the ability to meet the three year or less development schedule target.
- The realism of the proposed cost.
- The adequacy of the development approach for the mission, as evaluated by the Government, to develop the mission for less than the approximate \$30 million cost target to the Small-Class Explorer Program (not including launch services and mission operations costs subsequent to 30 days after launch).
- The overall merit of the management plan submitted.

The results of the evaluation process were subsequently presented to and reviewed by the Small-Class Explorer Categorization Panel, comprised of scientists from NASA and other Government agencies. The combined evaluation results were then presented to the Explorer Mission Review Board and to the Space Science and Applications Steering Committee (SSASC) Chairman, who conducted a detailed review of all proposal evaluations and the

procedures followed. Upon the Chairman's conclusion that the evaluation of proposals had been performed satisfactorily, the Associate Administrator, Office of Space Science and Applications was briefed, and a formal recommendation with appropriate supporting rationale was developed for his selection decision. A public announcement of the Associate Administrator's selection of the following four initial flight missions was made on April 4, 1989:

- Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX)
- Submillimeter Wave Astronomy Satellite (SWAS)
- Fast Auroral Snapshot Explorer (FAST)
- Total Ozone Mapping Spectrometer (TOMS)

Official notification letters were mailed on the same date to the principal investigators of all the selected and non-selected investigations.

INITIAL SMALL EXPLORER MISSIONS

The four selected missions offer a variety of space science investigations. Each mission will be discussed with emphasis on its instrumentation and spacecraft characteristics. The number of missions selected was purposely limited to the number of flight opportunities that could be realized over the next three to four years, in order to limit the queue of payloads awaiting flight. Three of the selected missions have been funded by NASA for initiation of work in Fiscal Year 1989.

Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX)

The first mission is SAMPEX (Glenn M. Mason, University of Maryland, Principal Investigator), and its characteristics are summarized in Table 1. The zenith-pointing satellite in near-polar orbit will carry out energetic particle studies of outstanding questions in the fields of space plasma physics, solar physics, heliospheric physics, cosmic ray physics, and middle atmospheric physics. The instruments can measure the electron and ion composition of energetic particle populations from ~0.4 MeV/nucleon to hundreds of MeV/nucleon using a coordinated set of detectors of excellent charge and mass resolution, and with higher sensitivity than previously flown instruments. While over the magnetic poles, SAMPEX will detect solar energetic particles, interplanetary particles, and galactic cosmic rays. The instruments will also observe precipitating magnetospheric electrons, which undergo interactions with the middle atmosphere.

The instrument payload consists of a complementary set of four high resolution, high sensitivity particle detectors, which are in an advanced state of development and will permit rapid implementation of the mission at a reasonably low cost. The SAMPEX mission is scheduled for launch in June 1992, and the spacecraft design concept is illustrated in Figure 1. The planned mission lifetime of at least three years will allow the solar studies to be carried out from immediately after the peak of the solar maximum into the declining phase of the activity cycle.

Table 1. SAMPEX Mission

- TYPE: SOLAR/ZENITH POINTER
- ORBIT: 580 KM CIRCULAR
82° INCLINATION
NOT SUN SYNCHRONOUS
- LIFETIME: 3 YEARS
- LAUNCH: JUNE 1992 - SCOUT LAUNCH VEHICLE
- SITE: WESTERN TEST RANGE
- SCIENCE: COSMIC AND HELIOSPHERIC PHYSICS
- INSTRUMENTS:
 - FOUR DETECTORS IN ADVANCED STATE OF DEVELOPMENT
 - LOW ENERGY ION COMPOSITION ANALYZER (LEICA) -- UNIVERSITY OF MARYLAND
 - HEAVY ION LARGE TELESCOPE (HILT) -- MAX PLANCK INSTITUTE, FRG
 - MASS SPECTROMETER TELESCOPE (MAST) AND PROTON-ELECTRON TELESCOPE (PET) -- CALIFORNIA INSTITUTE OF TECHNOLOGY
- SPACECRAFT: DESIGNED, BUILT AND TESTED AT GODDARD SPACE FLIGHT CENTER

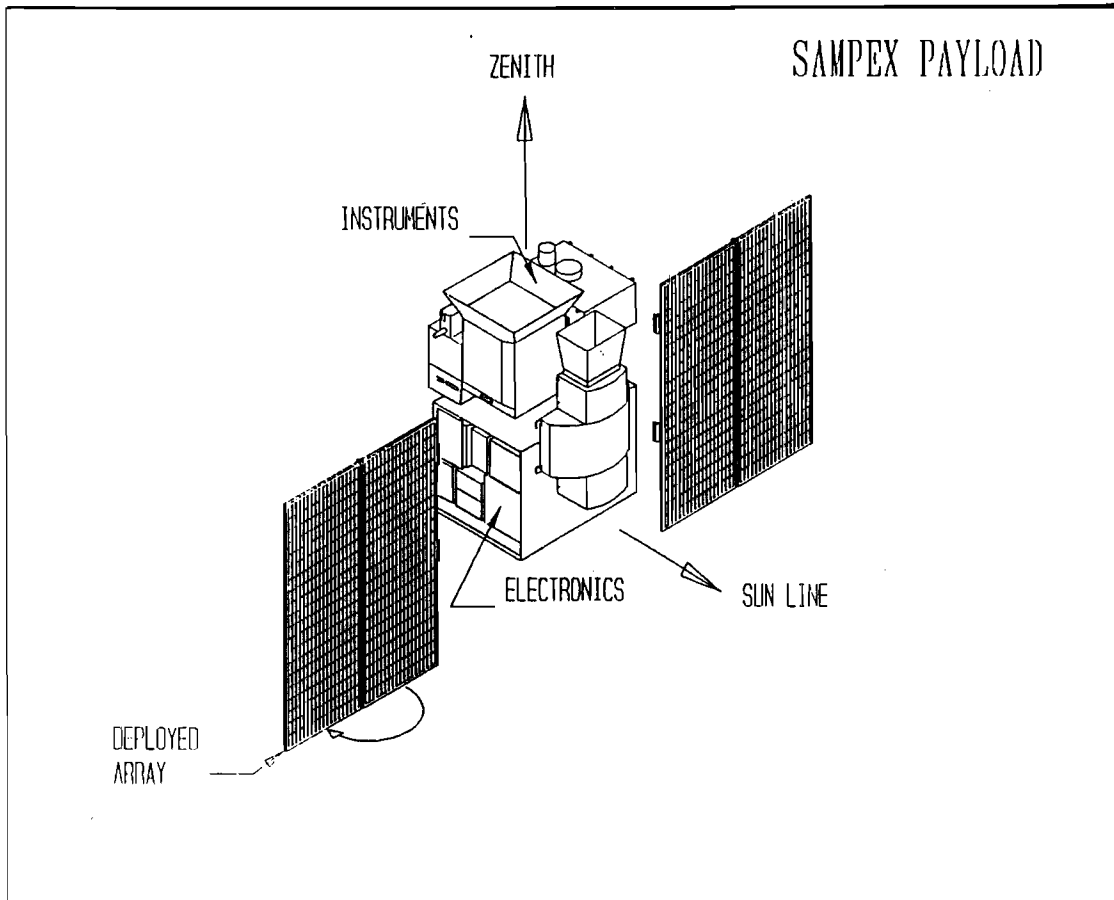


Figure 1. SAMPEX Design Concept

Each of the four particle detectors addresses a subset of the required measurements, and there is enough overlap in energy and response to allow intercalibration and partial redundancy. Two of the instruments, the Low Energy Ion Composition Analyzer (LEICA) and the Heavy Ion Large Telescope (HILT), were originally designed and constructed for Space Shuttle flight together in the Get-Away-Special program, but the instruments were never flown because of launch delays. The SAMPEX Small Explorer mission, however, will provide greatly improved scientific returns, because of the much longer exposure time with the satellite vis-a-vis the Shuttle flight. The other two instruments, the Mass Spectrometer Telescope (MAST) and the Proton/Electron Telescope (PET), comprise a single instrument package that was designed, and partially fabricated, to fly on the proposed U.S. spacecraft of the International Solar Polar Mission.

In order to reach the required orbit altitude to achieve a 3-year lifetime, the spacecraft weight and drag must be minimized. The best way to reduce drag was to minimize the cross-sectional area of the solar array panels, which in turn required a sun-pointed spacecraft. At the same time, there is a science requirement to maximize zenith pointing over the geomagnetic poles to collect particles. Therefore, designing the spacecraft to satisfy the science pointing requirement, while keeping the solar arrays pointed toward the sun to maximize power generation, has been a significant challenge. The resulting solar/zenith pointing system has been designed to accommodate both objectives.

The on-board Data Processing Unit (DPU), to be designed and built by the Aerospace Corporation, will perform a number of functions for the total experiment package. The DPU will: 1) provide command and data interface with the spacecraft; 2) monitor instrument data in order to set data collection rates and set priorities among instruments for data collection; 3) perform data compression; 4) provide timing signals; and 5) regulate the isobutane gas, which will continually flow through the ion drift chamber - proportional counter system of the HILT instrument.

The SAMPEX spacecraft will provide for on-board storage of data, so it will not be necessary to transmit data to a NASA ground station more frequently than once a day. The University of Maryland will process the raw data to assure correct timing and to remove overlaps, and then will merge the science data with attitude/ephemeris data supplied by NASA. Data processing and analysis will be performed at the participating institutions. Reduced data will be submitted to the NASA Space Sciences Data Center.

Submillimeter Wave Astronomy Satellite (SWAS)

The second mission, SWAS (Gary J. Melnick, Smithsonian Astrophysical Observatory, Principal Investigator), represents an innovative submillimeter investigation that builds on technology used in ground-based and suborbital instrumentation. The mission characteristics are summarized in Table 2. The investigation focusses on both pointed and survey (scanning) observations of dense galactic molecular clouds, in particular the lines of four species crucial to understanding cloud chemistry, energy balance, and structure. Large-scale observations of these lines are either extremely difficult or impossible from within the atmosphere.

Table 2. SWAS Mission

- TYPE: THREE AXIS, INERTIALLY STABILIZED, STELLAR POINTER
- ORBIT: 500-600 KM ALTITUDE
3° OR 37° INCLINATION
- LIFETIME: 3 YEARS
- LAUNCH: JUNE 1993 - SCOUT LAUNCH VEHICLE (OR EQUIVALENT)
- SITE: SAN MARCO, KENYA OR WALLOPS FLIGHT FACILITY
- SCIENCE: SUBMILLIMETER ASTRONOMY
- INSTRUMENTS:
 - BALL AEROSPACE -- INTEGRATED INSTRUMENT PAYLOAD
 - MILLITECH CORP. -- SUBMILLIMETER HETERODYNE RECEIVER
 - UNIVERSITY OF COLOGNE -- ACOUSTO-OPTICAL SPECTROMETER
- SPACECRAFT: DESIGNED, BUILT AND TESTED AT GODDARD SPACE FLIGHT CENTER

The SWAS instrumentation will be designed to achieve the maximum possible sensitivity by using a 55 cm diameter, off-axis Cassegrain antenna (largest possible within the Scout envelope), combined with state-of-the-art heterodyne receiver technology and the highest stability acousto-optical spectrometer (AOS) yet demonstrated at the desired frequencies. In less than 20 minutes of integration, SWAS will be able to measure the full range of predicted H₂O, O₂, CI, and ¹³CO abundances in any giant molecular cloud core within 1 kpc. Of particular importance, the 1.4 GHz bandwidth of the University of Cologne AOS will permit simultaneous observation of these four lines, thus maximizing the observing efficiency and substantially increasing confidence in the spatial coincidence of maps made in the various lines. The instrument package will include a solid-state star tracker for fine pointing.

The conceptual design for SWAS is still being developed by the NASA project office and the principal investigator's team. Further details will result from the definition studies to be performed over the next few months. While there will be a fairly high power requirement for this size spacecraft (65 watts average, 99.5 watts peak), the weight margin appears to be favorable. The quantity of data acquired each day will approach the data storage limit of 1 Gbit for the NASA standard tape recorder. Other spacecraft features will include a large, deployable sunshade, articulated solar arrays, and a small orbit adjust system. The instrument development and integration will be performed by Ball Aerospace Systems Group, and the submillimeter receiver, which uses two cooled Schottky barrier diode harmonic mixers, will be developed by the Millitech Corporation.

The three-axis, inertially stabilized, stellar pointing spacecraft will be launched into either an equatorial or mid-inclination orbit, depending on the results of ongoing tradeoff studies. Theoretically, the equatorial orbit would maximize sky coverage of the galactic plane, but operational considerations may favor the mid-inclination orbit with launch from NASA's Wallops Flight Facility. Since there are no expendables on SWAS, the lifetime of the experiment will be determined by orbital parameters, not storage limitations. The mission objective is to achieve a minimum life of three years in order to carry out the full proposed science program.

Fast Auroral Snapshot Explorer (FAST)

The third mission, FAST (Charles W. Carlson, University of California, Berkeley, Principal Investigator), is an investigation of auroral processes that expands upon a wide range of plasma phenomena discovered on previous satellite and rocket missions. Its high resolution measurements will greatly extend the observational capability of sounding rockets and should make a significant contribution to understanding the basic physics of auroral particle acceleration. The mission characteristics are presented in Table 3.

Table 3. FAST Mission

- TYPE: SPINNER
- ORBIT: 300 X 3500 KM ALTITUDE
76° INCLINATION
NOT SUN SYNCHRONOUS
- LIFETIME: 2+ YEARS
- LAUNCH: DECEMBER 1993 - SCOUT LAUNCH VEHICLE
- SITE: WESTERN TEST RANGE
- SCIENCE: SPACE PLASMA PHYSICS
- INSTRUMENTS:
SEVEN INSTRUMENTS BASED ON PREVIOUS SATELLITE AND ROCKET
EXPERIENCE - DEVELOPED BY:
 - UNIVERSITY OF CALIFORNIA, BERKELEY
 - LOCKHEED PALO ALTO RESEARCH LABORATORY
 - UNIVERSITY OF CALIFORNIA, LOS ANGELES
- SPACECRAFT: DESIGNED, BUILT AND TESTED AT GODDARD SPACE FLIGHT CENTER

The FAST spacecraft will operate in the natural plasma laboratory above the Earth's auroral zones. The innovative set of coordinated instruments with accurate time resolution will examine the electrodynamic causes of the beautiful and intricately complex auroral displays. Of special importance will be an attempt to reveal how electrical and magnetic forces guide and accelerate electrons, protons, and other ions in the auroral regions. This domain of the upper atmosphere is where the neutral atmosphere contacts the plasma-dominated solar system environment of the Earth. Energy and matter flow through this region, exciting the upper atmosphere into luminous displays controlled by electrical and magnetic forces. Capturing the essence of how these forces operate to produce the arcs, curtains, and other structures that dominate the night skies over Alaska, Northern Canada, Scandinavia, and Siberia has been a goal of scientists for many decades.

The FAST payload of seven instruments includes new sensors capable of detecting the flows of various types of matter, electrons, protons, and other ions with greater sensitivity and discrimination, as well as much faster sampling. Other sensors will measure the electrical and magnetic forces and simultaneously correlate these forces with their effects on the electrons and

ions at altitudes of 300 km to 3500 km. This region has been identified in earlier studies as the probable source for much of the energy that appears as auroral light emitted at about 100 km. In combination, the FAST instruments will have better temporal, spatial, and pitch angle resolution and dynamic ranges than any previous satellite measurements of auroral phenomena. The FAST observations will be complemented by data from other spacecraft at higher altitudes, which will be observing fields and particles and photographing the aurora from above. At the same time, auroral observatories and geomagnetic stations on Earth will provide measurements on how energetic processes observed by FAST affect the Earth as seen from the ground.

This mission is presently in the early stages of concept definition. It is clear that great care must be taken to limit spacecraft mass, and the principal investigator has already incorporated measures to conserve both power and mass allocations. A solid-state memory with 100 Megabytes capacity is proposed, as a large volume of data will be taken over relatively short periods of an orbit. The capability for real-time telemetry and command is anticipated, using the NASA Wallops ground station and a station at Poker Flats, Alaska. The scientific instrument package will include a Central Data Processing Unit with a specially designed, intelligent data handling and formatting system employing three microprocessors.

The spacecraft will be designed to spin about its axis normal to the orbit plane. It will deploy four radial electric field wire booms with tip-mounted spherical sensors, giving a total tip-to-tip length of 60 meters for each opposing pair of cables. Two spin axis stiff booms will also be used to deploy electric field sensors, and an articulated boom will deploy two magnetometers.

Total Ozone Mapping Spectrometer (TOMS)

The TOMS mission (Charles E. Cote, NASA Goddard Space Flight Center, Principal Investigator) will provide daily mapping of global ozone and through data analysis will permit the detection of significant trends, which is a high priority earth observing objective. A TOMS instrument is in operation now on the Nimbus-7 research satellite, which was launched in October 1978. The Nimbus-7 TOMS has far exceeded its original design life and cannot be expected to remain operational for much longer. The TOMS instrument measures the global distribution of total ozone in the earth's atmosphere, and it is an essential element in monitoring and understanding the changes that are occurring in the earth's atmospheric ozone layer. It has provided invaluable data on the development of the Antarctic Ozone Hole. The Small Explorer TOMS instrument would guarantee continuity in monitoring the depletion of the ozone layer due to injection of chlorofluorocarbons (CFCs) into the atmosphere.

Plans for the TOMS mission in the Small Explorer program are still in the formative stage, but the known mission characteristics are presented in Table 4. The development and launch of this mission will be accomplished on a schedule consistent with the development of a series of TOMS instruments for launch on international spacecraft.

Table 4. TOMS Mission

- TYPE: NADIR POINTER, 3-AXIS STABILIZED
- ORBIT: 900 KM CIRCULAR
90° INCLINATION
SUN SYNCHRONOUS AT NOON/MIDNIGHT
- LIFETIME: INDEFINITE
- LAUNCH: DATE TO BE DETERMINED; SCOUT-CLASS LAUNCH VEHICLE
- SITE: WESTERN TEST RANGE
- SCIENCE: UPPER ATMOSPHERIC SCIENCE
- INSTRUMENT: TOMS MULTISPECTRAL RADIOMETER
(SIMILAR TO NIMBUS-7 INSTRUMENT)
- SPACECRAFT: SOURCE TO BE DETERMINED

FUTURE PLANS

The Small Explorer program is designed to be responsive to the needs of the scientific community by providing frequent, open competition for new missions and prompt implementation of selected investigations. As noted earlier, NASA wants to maintain a steady rate of one or two launches per year without creating a long queue of payloads awaiting flight. Current plans call for the next A.O. in late 1990, from which missions for another three-year period would be selected. One procedural improvement being considered for this announcement is a standard proposal format that will: (1) promote the completeness of each proposal; (2) aid foreign proposers with interpretation of programmatic issues; and (3) conserve technical and cost evaluation effort. This standardization will be designed to assist investigators with the organization of their proposal material, which will be of mutual benefit to proposers and reviewers.

In concert with the A.O., there are plans for competitive procurement of new launch services from industry. Performance requirements will include enhancement of the present Scout launch vehicle capabilities to allow somewhat larger payloads and higher orbits. While one objective of the Small Explorer program is to contain experiment growth in complexity and cost, it is recognized that the current Scout capability severely limits, and even precludes, some potential investigations.

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