NASA'S SMALL EXPLORER PROGRAM

Its goal is to give scientists ready access to space by using expendable vehicles to provide frequent and relatively inexpensive launches of highly focused scientific satellites.

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Substantial publicity surrounds NASA's major scientific space missions. The Voyager interplanetary probes enthralled the public as they swept past the outer planets. The Hubble Space Telescope continues to attract great attention because of its ambitious objectives and large cost as well as its technical difficulties. NASA's deep space missions, such as Pioneer, Viking, Magellan, Galileo and Ulysses, and its "moderate" missions such as the Cosmic Background Explorer are further examples of large, long-term projects. Near-Earth spacecraft like the recently launched Gamma Ray Observatory and the many satellites of the planned International Solar Terrestrial Physics program also cost hundreds of millions of dollars. Indeed, with the attention given to programs involving humans in space—Space Station Freedom and the Manned Mission to Mars, for example—it might appear that NASA has only "big ticket" space missions.

In fact, this is not the case. NASA has a broad spectrum of small, less publicized scientific programs. (See the box on page 46 for a note on their history.) These programs are usually less well known not because their science is unimportant but primarily because their smaller budgets often do not lead to the same level of public scrutiny. Such diverse activities and instruments as the ground-based Infrared Telescope Facility on Mauna Kea, astronomy on the stratospheric Kuiper Airborne Observatory, high-altitude balloon experiments, suborbital sounding rocket observations and small-payload "getaway specials" on the space shuttle all are supported by these small, vigorous programs.

In the course of supporting first-rate scientific research, NASA's small-scale programs support shorter-term projects that are essential to the careers of many of our nation's scientists and engineers and their students. Because the opportunity to participate in the development of flight instrumentation is limited in the large programs, the smaller programs provide important "hands on"

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Small expendable launch vehicle. All but the first mission in the Small Explorer Program are scheduled to fly on airplane-launched winged Pegasus rockets like the one shown here. **Figure 1**

experience with scientific hardware for many scientists and students. Moreover, the frequency of launches of large NASA satellites will be lower in the immediate future. Combined with the long development time required for large projects, this fact prevents introduction of the latest scientific technology into space via large-scale missions. In contrast, smaller missions permit specialized, highly focused scientific investigations that often apply the most modern technological innovations.

To exploit these advantages of small projects, NASA's Office of Space Science and Applications has initiated a program at the NASA Goddard Space Flight Center in Greenbelt, Maryland, called the Small Explorer Program, or SMEX. SMEX is intended to support disciplines traditionally served by NASA's long-standing Explorer Program, which include astrophysics, space physics and upper atmospheric science. An exciting feature of SMEX is that one principal investigator proposes an entire mission and its experiments. The idea is to have the principal investigator firmly in charge of the entire mission, with the instruments being built by the PI and his or her team of coinvestigators. The team usually includes scientists at a variety of institutions who have worked together closely in the past. The result is an efficient, highly cohesive research effort.

An important additional goal of the SMEX program is to pass on to a new generation the precious knowledge of spacecraft design accrued by the present generation of engineers and scientists at the Goddard Space Flight Center. Specialized information often resides within a single individual who may be a veteran of numerous flight projects.

Announcement and selection

The original SMEX announcement of opportunity was released on 17 May 1988, with proposals due by 30 September 1988. The announcement articulated the following goals:

> The Small-class Explorer Program seeks to conduct scientific research of modest programmatic scope which can be launched within three years of selection. The program intends to provide a continuing opportunity for quickly implemented flights of small free-flyers to conduct focused investigations which complement major missions, prove new scientific concepts, or make significant contributions to space science in other ways. It is the goal of the program to obtain flight frequency of at least one flight per year. The scope of the missions is expected to be such that a single principal investigator will have responsibility for an individual investigation.

The cost per mission was to be limited, on average, to $30 million (1988 dollars), which includes both the instruments and the spacecraft but excludes launch services and mission operations costs beyond the first 30 days after launch.[1]

The announcement of opportunity offered a reliability and quality assurance policy unique to SMEX. This policy places a greater responsibility on the science team to insure that the instruments function properly in space. The policy emphasizes keeping designs simple and using predominantly "single string," or nonredundant, systems subjected to extensive preflight testing. This approach keeps costs as well as paperwork to a minimum. In implementing the reliability program, it is left to the judgment of the science team whether to use other than space-qualified components. The SMEX reliability policy accepts the greater risk inherent in a less formal program in exchange for the obvious benefits of lower cost and a more rapid flight schedule.

A total of 51 proposals were submitted in response to the first SMEX announcement of opportunity. On the basis of scientific peer review and technical and programmatic reviews, the associate administrator for NASA originally selected four missions for the SMEX program. A Scout rocket will carry the first SMEX satellite. Subsequent missions will fly on small expendable launch vehicles—winged Pegasus rockets launched from airborne carriers. (See figure 1.) NASA recently chose Orbital Science Corporation to provide the launch services for its next 8 to 12 SELV launches.

The first SMEX mission selected for flight is the Solar, Anomalous and Magnetospheric Particle Explorer, which is scheduled for a June 1992 launch. The principal investigator for SAMPEX is Glenn M. Mason at the University of Maryland.

Small Explorer Origins

America's exploration of space began with the launch of the first Explorer satellite in 1958. To date, NASA has built and launched over 60 Explorer spacecraft, which represent a continuous and important element of the nation's space program. Traditionally, Explorers were defined as spacecraft with capabilities intermediate between those of sounding rockets and orbiting observatories. They were reasonably inexpensive, could be developed quickly and provided frequent opportunities for space experiments. Explorers have fulfilled many roles; they have, for example, provided:

▷ the primary tool for the detailed study of particular regions of space and of specific physical phenomena

▷ a cost-effective method for addressing certain scientific problems

▷ a means for the flight demonstration of new spacecraft design concepts and hardware, especially instruments

▷ an opportunity to develop scientific research, engineering and project management capabilities

▷ the capability for a quick response to targets of opportunity

▷ an opportunity for international cooperative missions.

Explorers cannot play many of these roles when they become ambitious, scientifically or technologically complex projects requiring long development times and large budgets. These roles can be maintained only when scientists have frequent access to new Explorer missions. Thus the Small Explorer Program is in many senses a return to the original Explorer concept. (Adapted from Space Science Board, "A Strategy for the Explorer Program for Solar and Space Physics," Natl. Acad. P., Washington, D. C., 1984.)

The second SMEX mission is the Fast Auroral Snapshot satellite, which is slated for a September 1994 launch. The principal investigator for FAST is Charles W. Carlson at the University of California, Berkeley.

The third SMEX mission is the Submillimeter Wave Astronomy Satellite, which is scheduled for a June 1995 launch. The principal investigator for SWAS is Gary J. Melnick of the Smithsonian Astrophysical Observatory.

The fourth mission, the Total Ozone Mapping Satellite, has been transferred to NASA's Earth Probes program.

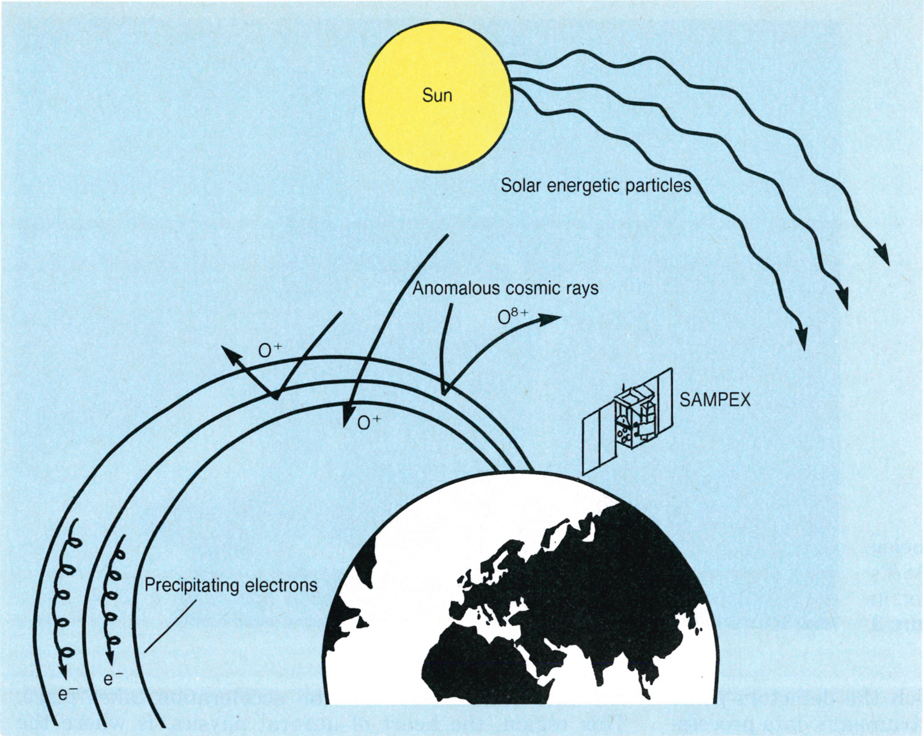
SAMPEX

Instrumentation for the Solar, Anomalous and Magnetospheric Particle Explorer includes a complementary set of four particle detectors with excellent charge and mass resolution and much higher sensitivity than instruments previously flown: the Heavy Ion Large Telescope, the Low Energy Ion Composition Analyzer, the Mass Spectrometer Telescope and the Proton/Electron Telescope. Prototypes of the first two detectors flew on the space shuttle in August 1989. The other two were originally approved for the US spacecraft of the International Solar Polar Mission, and their construction was under way when the US component of that mission was canceled. Thus these new instruments are in an advanced state of development and are being readied for SAMPEX quickly and at a remarkably low cost of $4.5 million.

SAMPEX will measure the electron and ion composition of particle populations with energies ranging from about 0.4 MeV/nucleon to hundreds of MeV per nucleon. It will detect these energetic particles from a zenith-pointing satellite in near-polar orbit. While over Earth's magnetic poles (see figure 2), the instruments will study the composition of anomalous cosmic rays, solar energetic particles and Galactic cosmic rays. At lower magnetic latitudes, the properties of Earth's magnetic field will allow determination of the ionization state of these particles at energies much higher than can be studied from interplanetary spacecraft. At subauroral latitudes, SAMPEX will also observe precipitating relativistic magnetospheric electrons, which undergo interactions within the middle atmosphere.

In the energy range below about 50 MeV/nucleon, there are at least six elements (He, C, N, O, Ne and Ar) whose energy spectra show large increases in flux above the quiet-time Galactic cosmic-ray spectrum. This "anomalous" cosmic-ray component is generally believed to represent neutral interstellar particles that drift into our solar system (that is, the heliosphere), become ionized by solar wind interactions or ultraviolet solar radiation, and are then accelerated. This model makes a unique prediction: The anomalous component should be singly ionized, an assertion for which there is only indirect evidence.[2] SAMPEX will make the first direct measurement of the particle charge state by using Earth's magnetic field as a giant charge-state spectrometer. If these cosmic rays are indeed singly ionized, then this component represents a direct sample of the local interstellar medium.

Solar flares frequently inject large populations of energetic heavy nuclei into the interplanetary medium.



Environment to be explored by the Solar, Anomalous and Magnetospheric Particle Explorer satellite. SAMPEX will study solar energetic particles, anomalous cosmic rays, Galactic cosmic rays and magnetospheric electrons. The data will help determine the source and composition of cosmic rays, the relation of the solar atmosphere to the origin and composition of the solar system, and the spectrum of relativistic electrons plunging into our atmosphere. **Figure 2**

The elemental and isotopic compositions of these particles provide information that is crucial for understanding the history of material in the solar system and for studying the acceleration and propagation of solar flares. High-sensitivity spectrometers on SAMPEX will have 1–2 orders of magnitude more collecting power than previous instruments and thus will determine these compositions with sufficient accuracy to differentiate clearly the solar source from other possible sources, such as Earth's magnetosphere.

Observations from geosynchronous orbit have found that the intensities of relativistic ($\gtrsim 1$ MeV) electrons can increase by orders of magnitude for periods of several days. These enhancements are related to the presence of recurrent high-speed solar wind streams and show a strong dependence on the 11-year solar cycle. Numerical modeling shows that when these electrons precipitate they can deposit large amounts of energy in the atmosphere at altitudes of 40–60 km, dominating other ionization sources at these heights.[3] Precipitating relativistic electrons may lead to substantial long-term increases in the levels of nitrogen oxides at these heights, with an attendant impact on local ozone levels via the reactions $NO + O_3 \rightarrow NO_2 + O_2$ and $NO_2 + O \rightarrow NO + O_2$. Thus relativistic electrons may provide a mechanism for coupling the 11-year solar activity cycle into the middle and lower atmosphere. It is therefore critical to determine the actual intensity and spatial extent of relativistic electron precipitation, as SAMPEX will do.

Galactic cosmic rays are a directly accessible sample of matter from outside the solar system. A spectrometer on SAMPEX will measure the isotopic composition of this high-energy matter, which contains a record of the nuclear history of cosmic rays. Cosmic-ray isotope observations have already revolutionized our thinking about both the origin and propagation of cosmic rays. For example, measurements have shown that ^{22}Ne is more than three times as abundant in cosmic-ray source material as it is in the solar system. Similarly, the abundances of ^{25}Mg, ^{26}Mg, ^{29}Si and ^{30}Si are all enhanced by a factor of about 1.5. SAMPEX will extend the search for isotopic differences between Galactic and solar cosmic-ray material to many other key elements.

The Heavy Ion Large Telescope is designed to measure anomalous cosmic rays near the intensity maximum of their spectrum. The high flux will allow statistically accurate measurements of the mass spectrum of the heavy nuclei and determination of the cutoff point at which Earth's magnetic field blocks the rays. These measurements are needed to determine the charge state of the anomalous rays and the charge states of energetic solar particles.

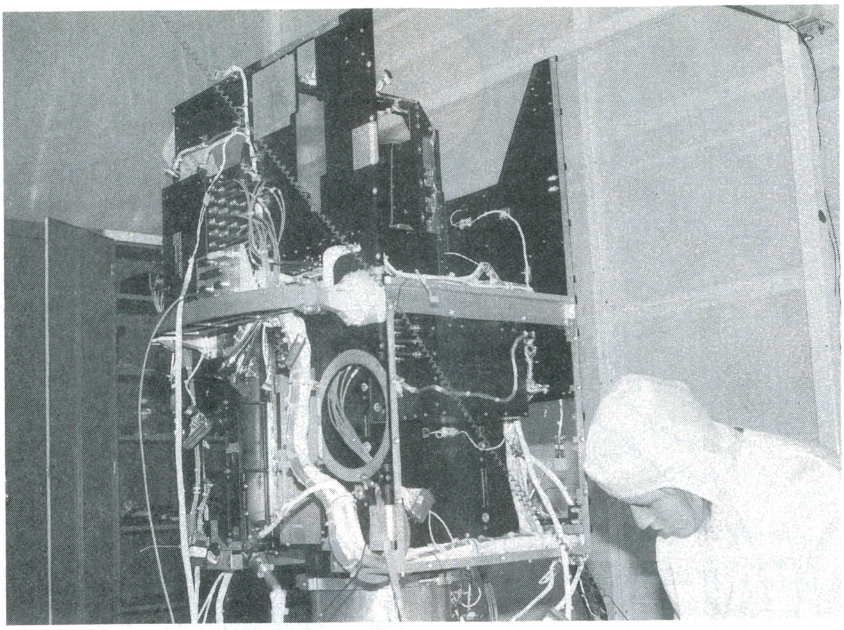
The Low Energy Ion Composition Analyzer measures elemental and isotopic abundances over the range of about 0.35–10 MeV/nucleon. It is a time-of-flight mass spectrometer that identifies the masses and energies of incident ions by simultaneously measuring their times of flight and their residual kinetic energies when they stop in one of four silicon solid-state detectors.

The Mass Spectrometer Telescope will measure the isotopic compositions of elements from lithium to nickel in the energy range from about ten to several hundred MeV per nucleon. The spectrometer will identify isotopes by the standard dE/dx vs E technique and will achieve a resolution of 0.3 amu, sufficient to resolve isotopes with abundance ratios of about 100:1.

The Proton/Electron Telescope system has an all-solid-state detector, which will allow the measurement of electron spectra from about 1 to 100 MeV.

These four detectors will be constructed at separate institutions and then integrated with the experiment's data processing unit. This approach requires only a single electrical and data interface between the SAMPEX experiment and the spacecraft.

The spacecraft (see figure 3) has a custom design to accommodate already-developed instruments in the tight volume of the Scout heat shield. The craft is stabilized by momentum wheels and will generate the power it needs by keeping its solar panels always pointed toward the Sun. It will rotate about the Sun-pointing vector in such a way as



Sampex spacecraft now being assembled and tested at NASA's Goddard Space Flight Center, in Greenbelt, Maryland. **Figure 3**

to maximize the time during which the detectors point directly away from Earth. The instrument's data processing unit will send telemetry packets to the spacecraft's data system, which will store data in a 26-megabyte solid-state memory. Every 12 hours the memory will be dumped to NASA's Wallops Island, Virginia, flight facility or to an alternate site. The spacecraft will carry a 36-month supply of isobutane for the Heavy Ion Large Telescope sensor, consistent with SAMPEX's planned minimum three-year lifetime; there will be no other expendables on board.

FAST

The Fast Auroral Snapshot satellite is also a custom-designed spacecraft that uses an integrated instrument approach. FAST's instruments include a three-axis set of 50-meter tip-to-tip electric field probes with additional inner sensors for wavelength and phase velocity measurements; Langmuir plasma density and temperature probes; vector fluxgate magnetometers for dc magnetic field measurements and search-coil magnetometers for ac measurements; an ion mass spectrograph; an electron spectrograph; and electron and ion spectrometers. Also included are a wave–particle correlator and waveform processors. The majority of the instruments are located in the spin plane of a torus that constitutes the central portion of the satellite. The top and bottom halves are essentially hollow structures that support arrays of solar cells. In orbit, long electric field booms and shorter magnetic field booms will unfold in the spin plane. (See figure 4.)

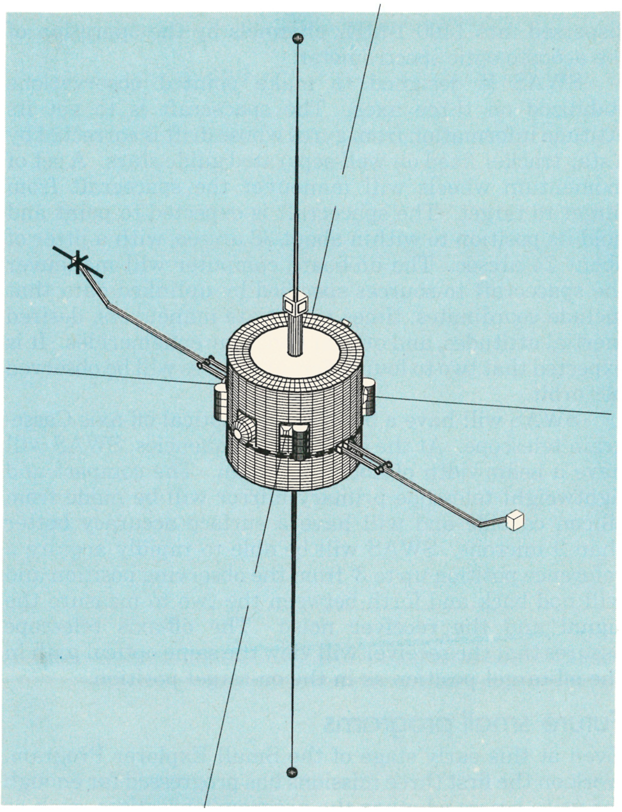
With a planned apogee of 4200 km, the polar-orbiting FAST satellite is designed to explore the microphysics of auroral zone plasma processes. (See figure 5.) The auroras are located in Earth's high-latitude regions, where the nearly vertical magnetic field lines electrically connect the upper atmosphere to distant regions in the magnetosphere. As charged particles trapped in Earth's magnetic field are accelerated, they enter the "loss cone" and precipitate into the atmosphere. There, via collisions with neutral atmospheric particles, they give off light. The fundamental questions about the physical mechanisms that generate the auroras concern processes at higher altitudes, where electric fields and charged particles interact and the electron acceleration takes place. This region, the heart of auroral physics, is where the FAST satellite will go and where its instruments will explore the rich physical processes with unprecedented detail.

Equipped with an array of interdependent instruments to measure fields and particles, FAST has a dual focus: to investigate the production of plasma waves, double layers, solitons and electrostatic shocks by electrons and ions, and to study the acceleration and heating of such particles by the waves and potential structures themselves.[4] Many aspects of FAST's science are central to understanding not only fundamental physical processes in Earth's environment but also basic plasma physics and acceleration processes in astrophysical plasmas.

The FAST small explorer investigation is built upon knowledge gained from several previous auroral experiments using satellites and rockets. In the last five years in particular, sounding rockets with high apogees (about 1000 km) and ultrafast time resolution have uncovered several key components of auroral acceleration processes—Langmuir solitons and double layers as well as narrow field-aligned electron distributions at the edges of the arc-shaped ion trajectories.[4] However, these rockets have only skimmed the lower levels of the main interaction regions. The philosophy of FAST is based on the fact that because auroral processes occur in very limited bands—typically two 10–15°-wide sectors surrounding each pole—high-time-resolution measurements need not be taken throughout the entire orbit. Instead, the instruments are programmed to take "snapshots" of the auroral acceleration phenomena, sometimes at rates as high as 1 megabyte/sec. The data will fill a 1-gigabit solid-state memory and will then be transmitted to the ground at a slower rate.

A very important aspect of the FAST small explorer mission is its linkage to scientific studies planned by several other teams of researchers in the space physics community. For example, campaigns are being formulated in which sounding rockets and dedicated ground-based all-sky cameras would operate in conjunction with coincident FAST orbits overhead. The launch decisions for the rockets would be based on real-time FAST data sent directly to the rocket range at Poker Flat, Alaska. In

Fast Auroral Snapshot satellite. The electric field detectors, which are represented by thin lines in the spin plane, span 50 meters tip to tip. Dc and ac magnetometers are deployed on 2-m booms. Electron and ion detectors are mounted on the body of the spacecraft. **Figure 4**



addition, FAST provides an important low-altitude complement to the impressive armada of high-altitude magnetospheric and solar wind satellites NASA expects to launch in 1993–95 as part of the International Solar Terrestrial Physics program. One of these satellites, POLAR, will take high-temporal-resolution images of the auroral oval from a vantage point of about 8 Earth radii, or 51 200 km. POLAR's global observations of auroral dynamics and morphology will be correlated with FAST's detailed particle acceleration observations. The FAST spacecraft is designed to operate for at least one year.

SWAS

The Submillimeter Wave Astronomy Satellite is a pioneering effort to make astrophysical observations in an extremely difficult region of the electromagnetic spectrum. Observations at wavelengths under 1 mm are challenging because many of the molecular transitions that astronomers wish to observe are so strong in Earth's atmosphere that any extraterrestrial view is blocked.[5] SWAS will overcome this difficulty by being the first submillimeter-wavelength radiotelescope to operate completely above Earth's atmosphere. It will have to pack all of the components of a radio observatory—antenna, receivers and acousto-optic spectrometer—as well as spacecraft systems into a lightweight and compact package. (See figure 6.)

The aim of SWAS is to elucidate the chemical composition, energy balance and structure of interstellar molecular clouds. It is known in broad outline that most of the interstellar gas in our Galaxy is located in molecular clouds and that in these clouds the gas cools, condenses and ultimately forms new stars and planetary systems. There seems to be a paradox, however, in that as a parcel of gas collapses due to gravity, its pressure and temperature increase, preventing further collapse. How then do interstellar clouds condense to high enough densities to form stars and planets?

The details of the processes that can lead to the formation of stars or planets are not known, because many fundamental questions remain: What are the major coolants of interstellar clouds? What are the reservoirs of carbon and oxygen (the most abundant elements besides hydrogen and helium) in dense clouds? What are the densities and temperatures of dense clouds? Chemical models of interstellar clouds predict that gas-phase oxygen will be in the form of O, O_2, H_2O or CO, while most of the gas-phase carbon will be present as either CO or C. We know that dense clouds are likely to be cold (under 35 K), and so the most effective way for their molecules and atoms to cool is to radiate away energy from low-J rotational transitions whose upper-state excitation temperatures are less than 35 K. CO, H_2O and O_2 have such transitions. Cooling occurs to a lesser extent through the radiation that produces the CI (that is, neutral carbon) fine-structure spectroscopic line.

Because very little is known about the abundances of H_2O and O_2 in molecular clouds, SWAS will have a dynamic observing strategy that will depend on what is seen. The SWAS mission has three main scientific goals. The first two are to measure the H_2O and O_2 lines or to place limits on their abundances. The third is to obtain large-scale maps of ^{13}CO and CI to correlate with maps of ^{12}CO and the strong CII (singly ionized carbon) lines. From a small number of ground-based and airborne observations, it is clear that SWAS should easily detect both the CI and ^{13}CO lines (the $J = 5$ to $J = 4$ transitions). SWAS will be able to obtain maps of the CI distribution that will reveal the structure and extent of photodissociation regions. The ^{13}CO line, in conjunction with other molecular emissions, should be a very effective tracer of warm and dense material in molecular clouds. The SWAS mission plans to obtain detailed $1° \times 1°$ maps of at least 20 giant molecular and dark cloud cores; each of these 1° squares will be made from a grid of measurements taken at 3.7-arcminute spacings. To accomplish these three goals SWAS must have a minimum lifetime of about 2.5 years.

SWAS's submillimeter radiometers are a pair of passively cooled subharmonic Schottky diode receivers built by the Millitech Corporation, subcontracting for the Ball Aerospace Systems Group. The receiver diodes will be cooled to about 150 K, thus achieving receiver noise figures of 2500–3000 K, single sideband. Local oscillator power is obtained by frequency tripling the output of indium phosphide Gunn oscillators to one-half the frequency of the receivers, for subharmonic operation.[6] The third major component of the SWAS instrument is the acousto-optic spectrometer built by the University of Cologne. In an acousto-optic spectrometer the electromagnetic signal sets up acoustic waves in a crystal, and these waves deflect a laser beam. The outputs of the two SWAS receivers are combined to form a final intermediate frequency, which extends from 1.4 to 2.8 GHz and is dispersed into 1400 1-MHz channels by the operation of the acousto-optic spectrometer.

SWAS is designed to make pointed observations stabilized on three axes. The spacecraft is to get its attitude information from gyros whose drift is corrected by a star tracker fixed on well-separated guide stars. A set of momentum wheels will maneuver the spacecraft from target to target. The spacecraft is expected to point and hold its position to within about 38 arcsec, with a jitter of about 24 arcsec. The on-board computer will maneuver the spacecraft to sources specified by uplinked data that include coordinates, times to initiate maneuvers, desired inertial attitudes, and orbital and solar ephemerides. It is expected that two to four different sources will be observed per orbit.

SWAS will have a 55×71-cm elliptical off-axis Cassegrain telescope. At the operating frequencies, SWAS will have a beamwidth of about 4 arcmin. The compact and lightweight telescope primary mirror will be made from silicon carbide and will have a surface accuracy better than 9 microns. SWAS will be able to rapidly acquire a reference position up to 3° from the observing position and will nod back and forth between the two to measure the signal and the receiver noise. The off-axis telescope assures that the receiver will view the same optical path in the off-target position as in the on-target position.

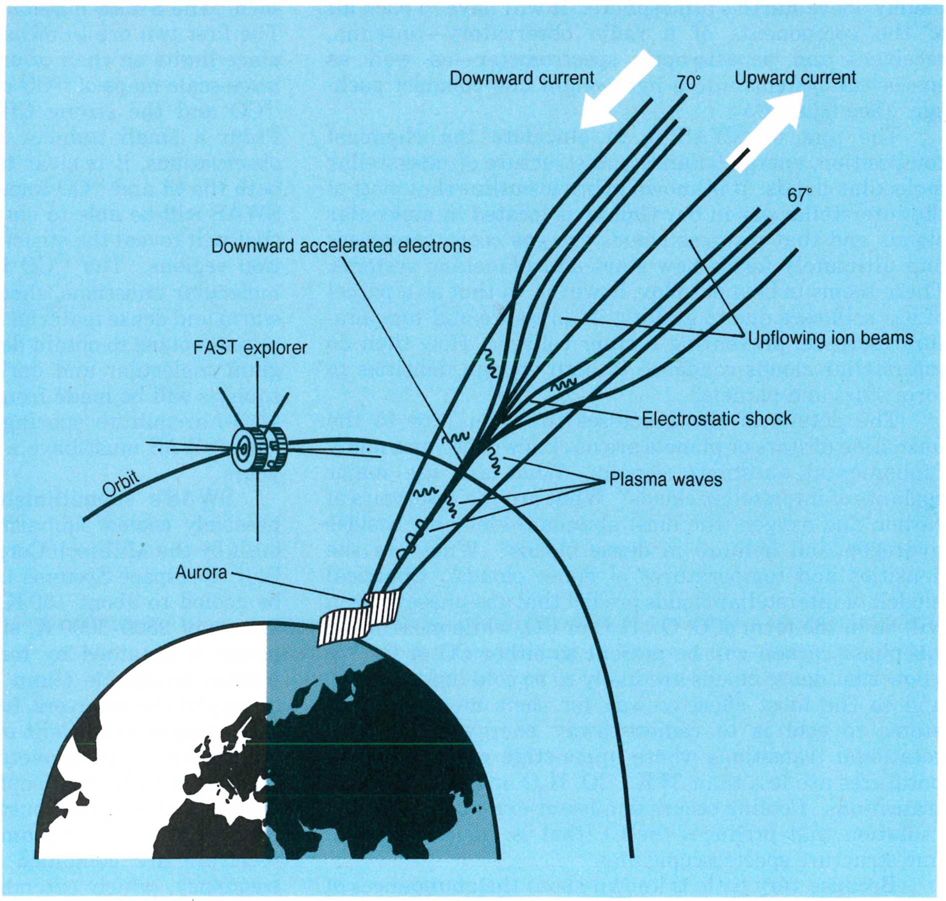
Future small programs

Even at this early stage of the Small Explorer Program, work on the first three missions has progressed far enough for us to assess whether the program's promises, such as low cost, rapid development, and small but technically capable satellites, can be realized. One goal of the SMEX program, the rapid development of small satellites that can perform important scientific research, appears well within reach. The SAMPEX mission is on schedule for a June 1992 launch, which means that the total development period for this satellite will have been about three years. The FAST mission is on track for a September 1994 launch.

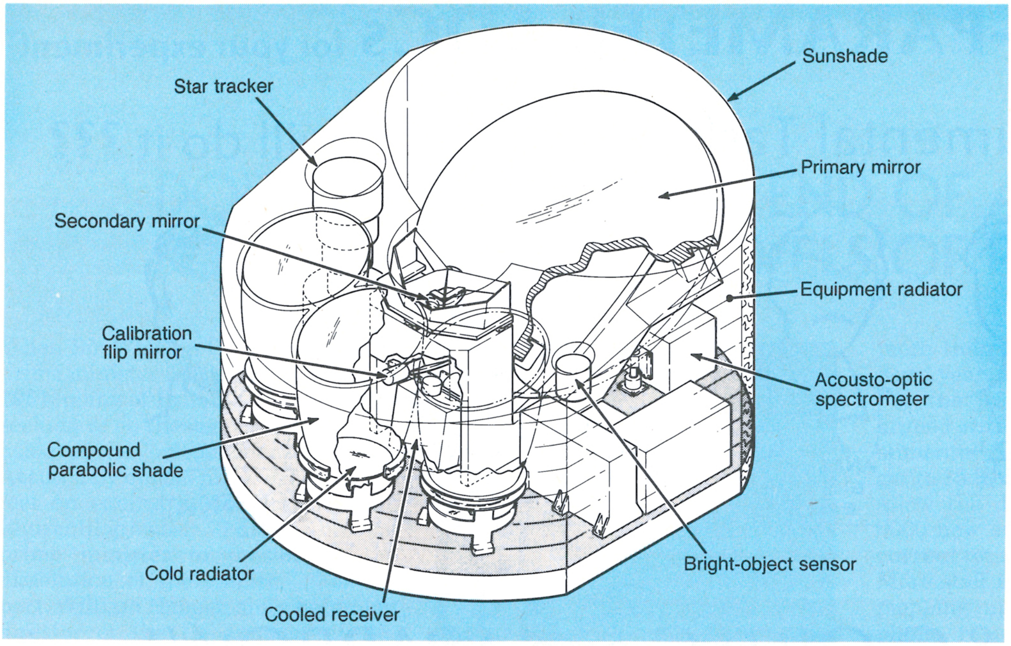
The scientific scope and technical diversity of SAMPEX, FAST and SWAS support the basic small explorer philosophy that instruments and spacecraft systems limited to small packages can yield large scientific dividends. One must remember that an entire SMEX payload is smaller than half a laboratory rack of equipment. There was an implicit assumption in the SMEX announcement of opportunity that there would be a common spacecraft carrier capable of accommodating all instruments. In practice, however, custom spacecraft designs have to be developed because of space limitations. Doing this requires the science teams to work closely with the spacecraft builder to come up with ingenious ways of overcoming technical hurdles and assuring that the necessary trade-offs do not jeopardize science goals. Simply "providing an instrument" to the SMEX project would not have sufficed for any of the first three missions.

Perhaps the most important promise of the Small Explorer Program, to provide frequent access to space for outstanding science missions, can be fulfilled only by maintaining a steady schedule of follow-on SMEX missions.[7] Launching one mission a year is an important goal that the SMEX project can meet given adequate funding and personnel. One approach that will help advance this goal is to cap the cost of future SMEX missions at $30 million or some similar figure that can fit within the SMEX budget.

The need to develop three vastly different types of



FAST will study the roles of waves and particles in the generation of auroral phenomena. Instruments on the satellite will make high-time-resolution measurements of electric and magnetic fields and of the acceleration of charged particles. FAST will detect auroral phenomena between approximately 67° and 70° latitude. **Figure 5**



Submillimeter Wave Astronomy Satellite instrument configuration. SWAS is being designed now and will be built by the Ball Aerospace Systems Group for the Smithsonian Astrophysical Observatory. It will study the chemistry, dynamics and physical conditions of molecular clouds and regions where stars and planets form. Specifically, SWAS will investigate H_2O, O_2 and CO as major reservoirs of carbon and oxygen in dense molecular clouds; H_2O, O_2, CI and CO as the dominant coolants in collapsing clouds; and the density and temperature within dense molecular clouds. **Figure 6**

spacecraft and attitude control schemes has given the SMEX project staff the experience to devise creative solutions and yet maintain a rapid schedule of launches. And at the rate of one launch per year, the SMEX project will quickly build up considerably more experience so that it can readily adapt to a broad array of scientific requirements. Gaining this flexibility and adaptability can also be viewed as achieving the project's secondary goal of maintaining an experienced corp of engineers that can act as a mainstay of a satellite program.

An announcement of opportunity for a second set of SMEX missions is expected in 1992. The new missions will undoubtedly incorporate changes that reflect the experiences of the first set of missions. The accepted missions may be required to have a short period of definition at a low level of funding before proceeding to the development phase. This will speed up the mission development cycle by enabling each mission to proceed confidently into its development phase and will thus help to maintain the goal of one launch per year. To avoid unnecessary reliability requirements, the next announcement should more clearly define the quality assurance standards. A related issue is a proposed 18-month limit on the lifetime of future SMEX missions. A year is too little time to accumulate data in orbit, whereas missions running longer than 18 months would begin to overtax the SMEX project as more and more satellites were launched. This limitation is also driven by a desire to relax reliability requirements, which have to be more stringent for longer missions.

A great deal of hard work remains to be done by the SMEX project and science teams, but once SMEX's goals are realized a critical resource will be available to the science community—ready access to space for scientific research on satellites.

We wish to acknowledge many useful discussions with Charles Pellerin, George Newton and David Gilman of the astrophysics division at NASA headquarters. We also thank Orlando Figueroa and his team at the Goddard Space Flight Center SMEX project office for extensive support and advice. Finally, we thank the first SMEX principal investigators—Glenn Mason, Charles Carlson and Gary Melnick—for material included in this article.

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