1 AEROSPACE AMERICA JANUARY 2010

January 2010

AEROSPACE AMERICA

Kepler's search for Earth-like planets

Conversation with Gen. Norton A. Schwartz

New capabilities for GPS II/III

A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

Small Explorers with big benefits

Although the public's attention usually focuses on larger spacecraft with high-profile missions, it is often NASA's small satellites that make the most surprising and useful discoveries. Fast-track schedules, low launch costs, and mission flexibility are among the key benefits of these innovative Small Explorer spacecraft.

by J.R. Wilson
Contributing writer

NASA's purpose is to push the frontiers of exploration and knowledge in aviation and space. Public attention, however, focuses mainly on the agency's big, expensive space efforts—manned lunar missions, robotic explorations of the planets, moons, asteroids, and comets in our solar system, and specialized telescopes seeking other Earth-like planets in our galaxy or previously undiscovered galaxies in the universe.

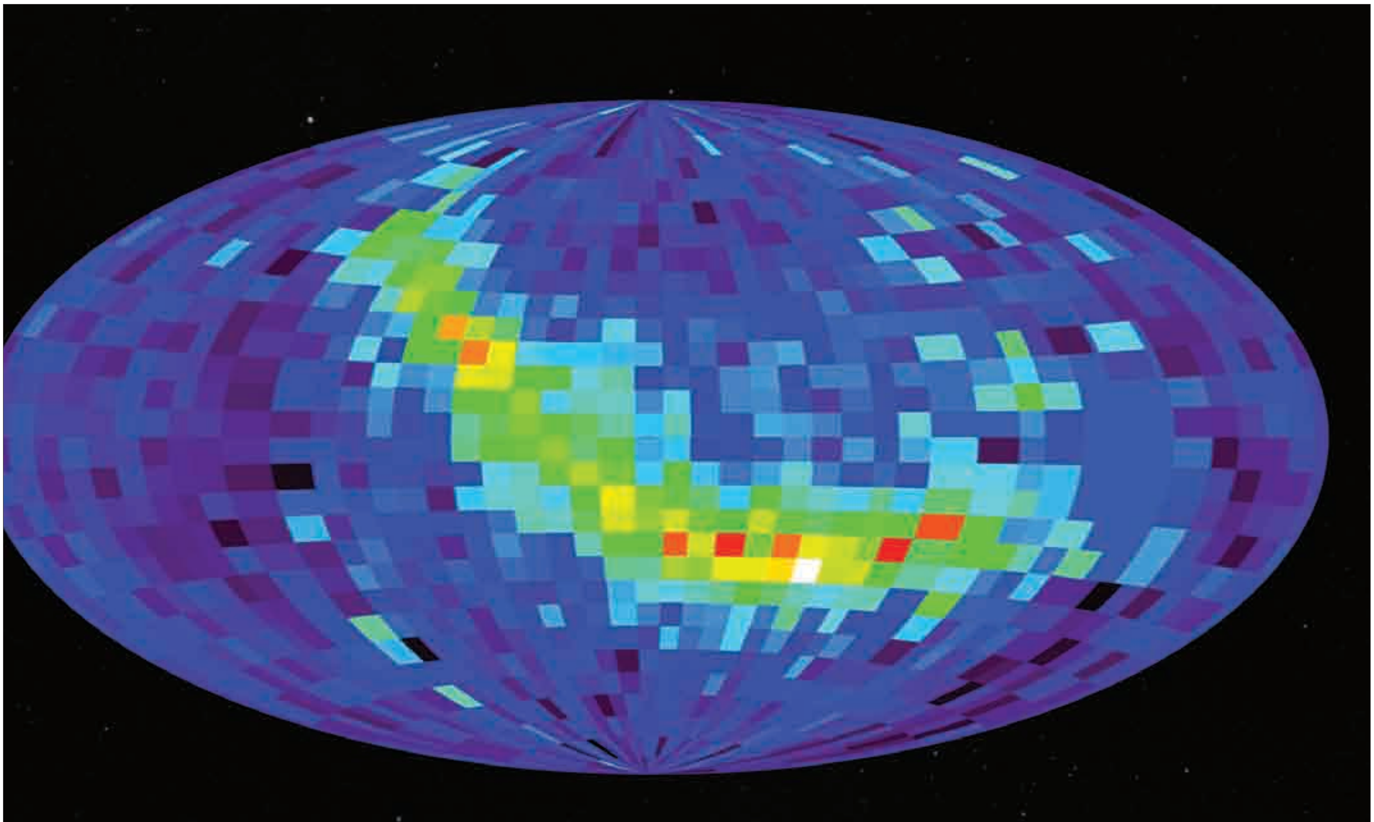
However, some of the most useful—and surprising—discoveries in NASA's five-decade history have come from small satellites, often sent aloft via small, inexpensive launchers or tacked onto large rockets when space was available. While such missions have been part of the NASA portfolio from the beginning, since 1992 they have been formalized in four categories of Explorers programs:

•Medium-class Explorers (MIDEX): Their missions do not exceed $180 million (in FY02 dollars) and are under the direction of a principal investigator (PI).

•Small Explorers (SMEX): Their PI-led missions do not exceed $105 million (in FY08 dollars).

•Missions of Opportunity (MoOs): These are non-NASA space missions of any size, having a NASA cost of less than $70 million (in FY08 dollars). MoOs are conducted on a no-exchange-of-funds basis with the organization sponsoring the mission. Proposals are solicited in each announcement of opportunity issued for both SMEX and MIDEX investigations.

•University-class Explorers (UNEX): The least expensive of the lot, these are



This sky map was produced with data that two detectors on the IBEX satellite collected during six months of observations. The detectors measured and counted particles scientists refer to as energetic neutral atoms.

launched by a variety of low-cost methods. NASA currently has suspended UNEX missions for lack of inexpensive launch opportunities.

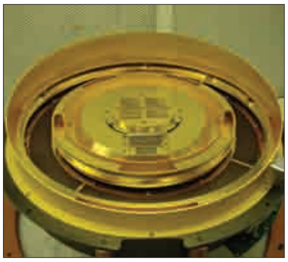
Breaking new ground

The first SMEX mission was the Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX), launched on July 3, 1992, by a Scout rocket. SAMPEX quickly entered the history books with the discovery of a new belt of trapped interstellar heavy nuclei circling the Earth within the inner Van Allen radiation belt—itself discovered by NASA's Explorer I satellite in 1958.

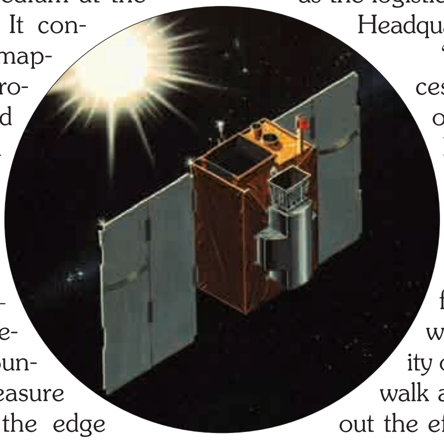
SMEX satellites have relied on the least expensive launch vehicles available, primarily the Orbital Sciences Pegasus rocket, which is first carried aloft with its payload by a Lockheed L-1011 converted for that purpose. The Pegasus is dropped from the aircraft, then ignites its own rocket to lift its payload into LEO.

IBEX, the Interstellar Boundary Explorer, launched on October 19, 2008, featured an innovation that broke new ground for future SMEX missions: A separate solid rocket motor (SRM) was attached to the satellite, enabling it to move from LEO to the near-lunar orbit required for its mission.

"Pegasus can fly about 1,000 lb to LEO; we used about 70% of that for the extra rocket and put a 300-lb IBEX satellite on top of that, basically using Pegasus as a first stage," IBEX PI Dave McComas tells *Aerospace Amer-*



IBEX has two sensors, IBEX Hi (seen here) and IBEX Lo. Each time an energetic neutral atom comes into one of the sensors, it is recorded; at the end of six months of that data scientists will have a picture of the entire 360° longitude celestial sphere. (Photo courtesy Southwest Research Institute.)



SAMPEX, launched by a Scout rocket, was the first SMEX mission.

ica. "So now there is a proven launch capability other small science missions can use. We were only about 10 lb away from leaving Earth orbit, so the same launch technique could be used to get to L-1 or the Moon, or even other planets. That's a really cool sideline of this, developing a new launch capability for NASA as part of our Small Explorers program.

"It took a lot of effort. We bought two SRMs, testing one and flying the second, and had to figure out a lot of rocketry rarely done by science teams—maybe never done by a science team before. Orbital was the lead on that work, although we also worked on it and brought in other experts as well. We were the prime, they were our subcontractor, so we retained overarching responsibility."

Mapping the heliosphere

IBEX's science objective was to discover the nature of the interactions between the solar wind and the interstellar medium at the edge of our solar system. It conducted the first complete mapping of the heliosphere, a protective boundary of solar wind traveling at 1 million mph and preventing about 90% of galactic radiation from entering the solar system. IBEX used two energetic neutral atom (ENA) sensors—one on each side of the spacecraft, perpendicular to its Sun-pointed spin axis—to measure particles coming in from the edge of the solar system, roughly 100 times farther out than the Earth is from the Sun.

As the spacecraft spun at four rpm, the ENA measurements were converted to pixels, building a crescent-shaped piece of the map. As it tracked the Sun, the sensors' circular swaths moved across the sky, gradually creating a complete image of the heliosphere and its interaction with interstellar radiation.

Without the heliosphere, radiation levels would make manned spaceflight, even to Earth's Moon, extremely dangerous, if not impossible, according to McComas, who is assistant vice president of the Space Science and Engineering Division of the Southwest Research Institute in San Antonio, Texas.

McComas compares the IBEX map to an artisan weaving a colorful pattern on a loom, one thread at a time.

"For the first time, we're sticking our heads out of the Sun's atmosphere and beginning to really understand our place in the galaxy,"said McComas following the October 2009 release of the sky map image. "The IBEX results are truly remarkable, with a narrow ribbon of bright details or emissions not resembling any of the current theoretical models of this region."

Managing for success

Although McComas' team went further than most, having full responsibility for every aspect of a SMEX mission is part of the job description for a PI.

"The PI formulates and manages the mission. We'll provide support to the PI in any way we can, such as providing expertise he may not have and backing him up with that resource, but the PI is really the architect of the mission, from the science to implementation," says Joe Dezio, Explorers deputy program manager at NASA Goddard. "One of our functions is to pass the budget on to him as the logistics interface with the [NASA] Headquarters line item budget.

"Our job is to make him successful. Period. But there is one caveat—while it is the PI's mission and team, as long as taxpayer money is involved, we have to be accountable for the success and application of that funding, so we still have what we call technical authority on the mission. We can't just walk away from the PI. Throughout the effort, we support all the reviews and have our own standing review teams mixed in with the PI's. So it is a bit of a strange mix—the PI's team and architecture, but we still have technical authority and must follow developments closely enough to assure everyone it will be successful on orbit."

Speed is key to a SMEX mission, which typically seeks to use the best available technology to learn something new before another generation of technology passes it by. As a result, the ideal SMEX concept takes about 36 months from initial proposal to launch, compared to an average of seven years for a standard NASA satellite program.

"We like to see about 2.5 years' development time, although sometimes it takes a bit longer," says Richard Fisher, director of the Heliophysics Division of NASA's Science Mission Directorate, which is responsible for approving Explorer missions. "The launch vehicles are at the 200-kg level for total payload, which usually means a single instrument or set of sensors, such as particle sensors, and a simplified data stream with one instrument or instrument suite.

"The payloads that have been selected have been pretty much equally divided between astrophysics and heliophysics or space science. SMEX is operated out of the Heliophysics Division, but for the benefit of both groups. However, the program is not shared in that the missions go from one to the other."

Outside the box

Unlike larger NASA missions, which are chosen on the basis of how well they fit into the national goals and priorities identified about every 10 years by the National Academy of Sciences, the Explorers program is designed to allow outside scientists to propose the science to be investigated. More often than not, that involves rapidly following up on a new discovery or theory and, often, finding something no one had expected or thought to explore.

"IBEX, for example, is a unique mission attempting to image the protective bubble that shields us from cosmic radiation and particles from the galaxy. My view is this relatively small, rapidly done experiment will change textbooks forever. That's an example of a good SMEX mission—and something not part of a national goal identified by the decadal survey," says Fisher.

But not being part of the formal NASA research program also has its drawbacks.

"We have gone through a bit of a dry spell for access to space to be in the right price range for Explorer missions," Dezio notes. "We got used to Scout and Delta vehicles, which were modestly priced, from $50 million to $70 million in the 1990s, which was a reasonable price for access to space. Back then, we scheduled about one every 12-18 months.

"In the past few years, the Pegasus vehicle has become one of the workhorses for the smaller missions. And there is competition coming into play with the Falcon [privately developed by SpaceX], which is adding to the access to space. And, of course, the [Orbital Sciences] Taurus is developing, taking the smaller end of the [retiring] Delta II market, and Minotaur [ICBMs converted for civilian launches by Orbital], which may be a little more capable than the Taurus. There may be more coming down the road, but Falcon and Pegasus are the only viable ones we have now."

Because of their comparatively low cost, SMEX missions are given more leeway on risk than larger satellites requiring more expensive launchers. They also tend to have shorter active life spans—typically only one or two years, although McComas believes IBEX may have enough reserve fuel to continue mapping operations for a full decade.

Birth of a mission

A Small Explorer begins with a NASA announcement of opportunity, usually including several missions in the SMEX or MIDEX range. Scientists then submit proposals for peer review, both within NASA and by non-NASA experts in the related fields.

"They make a judgment about cutting-edge science that is technically feasible. Once that determination is made, the associate administrator for science will look at the distilled evidence and make a selection," Fisher explains. "We like to offer a range of sizes of flight opportunity, from suborbital with high-altitude balloons and sounding rockets up to MoOs and SMEX and MIDEX.

"It is not uncommon for scientific knowledge to change from one mission to the next, and the scientific community is extremely good at evaluating and imaginative in using whatever opportunities there are. So people will propose the best science, which shows up in various places. You also get a lot of cross-fertilization, where an investigator may submit a proposal that is rejected, for whatever reason, then improve it until it is highly honed and focused."

For the last competition, 49 proposals were deemed compliant with all stated requirements—17 MoOs and 32 SMEXs. A second competition reduced that to six chosen for a concept development, SMEX study along with about a half-dozen MoOs.

"At that point, you have about 20% of the SMEX proposals still in play. Now we will have to make a decision about downselecting to one to three of those," Fisher says. "That will depend on a number of things, including future obligations of the program, which is basically an economic problem. You also don't want to stretch things out, because the science may become obsolete the longer you wait, so there is a balance between the time for development, funding rate, and science."

(Continued on page 41)

The early Explorer missions were launched on less expensive rockets like the Scout.

Today, Pegasus and Falcon 1 are two options for launching SMEX satellites.

Future prospects

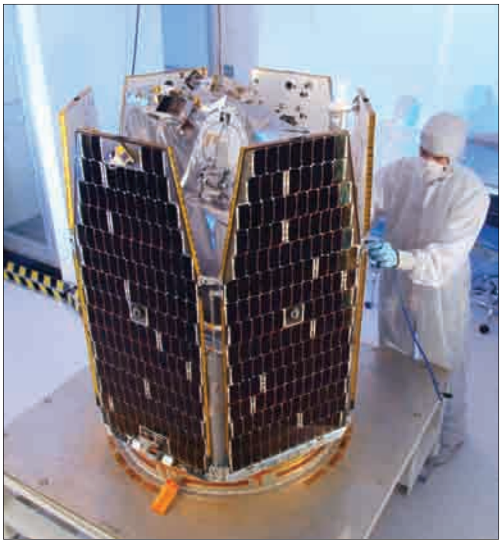
Nick Chrissotimos, Explorers program manager at Goddard, says they are still looking at a rate of 12-18 months between missions.

"And we like to mix those up a bit, so we're proposing to [NASA] Headquarters that we fly perhaps two SMEXs, then a MIDEX, then two SMEXs, another MIDEX, etc.," he says. "We can modify the rate depending on what we can afford. Headquarters gives us a guideline as to what kind of money they are thinking about, then we model what kind of missions that money will support—three SMEXs, two SMEXs and a MIDEX, etc.

"Up to now, I don't think the SMEXs have had as much breakthrough science as the MIDEXs. COBE [the Cosmic Background Explorer, winner of the Nobel Prize for physics in 2006], which mapped the background, was a MIDEX launched in 1989. SWIFT, launched about three years ago, also was a MIDEX and is doing really great science in gamma-ray burst activity, looking for black holes and leading to pretty astounding information on how black holes work, how stars collapse, and what's happening in the middle of quasars."

Even so, Chrissotimos adds, as newer and more advanced tools become available—especially smaller electronics—he expects SMEXs to contribute even more to the advancement of science.

"The SMEXs contribute a lot, and I think they will start coming more into their own as the scientists get newer and better tools for observations that they can put on smaller spacecraft. Given the last decade of efficient chips, there is more capability built into smaller buses than we had before. So scientists can put a lot of potential into SMEX missions that eventually will lead to more science breakthroughs," he says.



The AIM spacecraft, seen with its solar arrays in stowed configuration, will look at extremely high-altitude clouds floating over the poles. (Image credit: NASA/Orbital Sciences.)

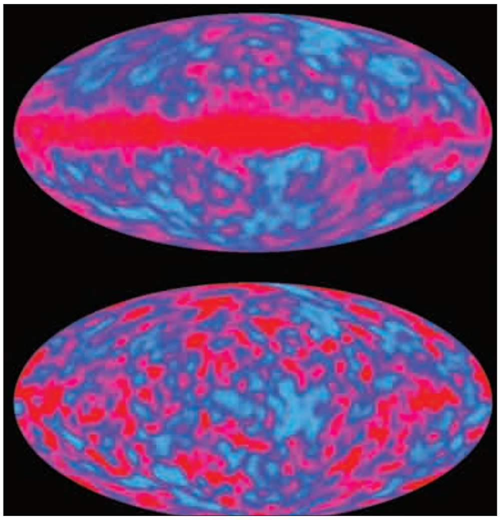
In addition to IBEX, Chrissotimos pointed to the 2008 launch of AIM (Aeronomy of Ice in the Mesosphere), which is looking at extremely high altitude—and rarely observed—clouds floating over the poles, as an example of that growth.

"Those observations will change our thinking about how vapor gets up that high, what are [these clouds] composed of, how do they work," he says. "So there is a lot of good science being done by the SMEX missions, and I expect that not only to continue but to improve as the technology allows smaller and more efficient systems to be built."

Although NASA was in a state of uncertainty during the four months it took President Obama to find a new administrator, Fisher is moving forward on the assumption the Explorers budget line will remain intact.

"Our plan continues the Explorers program out beyond 2020," Chrissotimos concludes. "We never know what will come over the transom, in terms of science. The chief scientist at NASA says the Explorers program is an example of rampant scientific capitalism—winner takes all, the best science at the lowest price. And, while I'm an advocate, I'd say that is true.

"The biggest change I anticipate—and I'm excited about that—is a slow change in launchers. In the next few years we will see other options for SMEX and MIDEX as new launchers come out of the commercial world. I believe that will have considerable impact on the program, because it will alter prospects for payloads, perhaps to L-2 or L-5. So I would anticipate growth in that area, and increasing complexity."



These famous maps of the cosmic microwave background anisotropy were formed from data taken by the COBE spacecraft, a SMEX mission.

Small Explorers
(Continued from page 35)