With the successful development of a geophysics program and seismic network extending into eastern, southern, and western Africa, further expansion of AfricaArray is now under way to include other areas of the geosciences. Current efforts are also focused on building science capacity more broadly, especially in fields relevant to solving problems associated with global change, the sustainable use of natural resources, and other pressing environmental issues.

To this end, in January 2010 funding was obtained from the U.S. National Science Foundation to upgrade the network by adding Global Positioning System (GPS) receivers and automated weather stations to many of the seismic stations, and in August 2010 installation of the new equipment began. In addition, workshops were held in Washington, D. C. (June 2010), and Johannesburg (November 2010) to obtain community input on a new science plan for AfricaArray that includes the areas of atmospheric science, climate science, geodesy, geography, hydrology, and space science, in addition to geophysics.

The current network (Figure 1) consists of 12 stations with collocated broadband seismometers, GPS receivers, and automated weather sensors; 1 with a collocated broadband seismometer and GPS receiver; 27 with broadband seismometers; and 1 with just a GPS receiver. An additional nine stations with collocated broadband seismometers, GPS receivers, and automated weather sensors will be added to the network by the end of 2011. Near–real time data transmission is available for some of the stations, primarily in southern Africa, while data are manually downloaded from data loggers at the majority of stations.

Information about the seismic equipment and access to the seismic data can be obtained from the IRIS data management facility under AfricaArray's network code of AF (http://www.iris.edu/mda/AF). Information about the GPS and meteorological equipment and access to the data are available through the UNAVCO data management facility (http://facility.unavco.org/data/data.html) by searching on AfricaArray.

Opportunities for Involvement

New partners are sought to help with the expansion of the network and research and education programs into all areas of the geosciences. With new partners the network can be made more dense, expanded geographically into other parts of Africa, and diversified through the addition of other environmental sensors to selected stations. Although the network has been constructed as a research facility, through new partnerships it could be upgraded into a real-time network for supporting disaster risk reduction.

New partners are also sought to promote the use of the network to build human scientific infrastructure in Africa. The network provides opportunities for existing programs to expand their activities through on-site technical training and the use of data for student and postdoctoral research; any efforts to strengthen and expand this are welcome. Information about becoming an AfricaArray partner can be found at http://www.AfricaArray.org.

Acknowledgments

Support from the many AfricaArray partners is gratefully acknowledged. Major funding for AfricaArray has been provided by the U.S. National Science Foundation (Division of Earth Sciences, Directorate for Geosciences; Partnerships for International Research and Education program, Office of International Science and Engineering) and South Africa's National Research Foundation.

—Andrew A. Nyblade, Pennsylvania State University, University Park; E-mail: nyblade@psu.edu; Ray Durrheim, University of the Witwatersrand, Johannesburg, South Africa; and Council for Scientific and Industrial Research, Auckland Park, South Africa; Paul Dirks, James Cook University, Cairns, Queensland, Australia; Gerhard Graham, Council for Geoscience, Pretoria, South Africa; and Roger Gibson and Susan Webb, University of the Witwatersrand

NEWS

Perspectives on More Than 3 Decades of the Voyager Mission

PAGE 163

Voyager 1 and Voyager 2, twin NASA probes that were launched from Cape Canaveral, Fla., in the summer of 1977 during a once-every-175-year alignment of the solar system's giant outer planets, changed our understanding about those planets—Jupiter, Saturn, Uranus, and Neptune—as well as the 4 dozen moons the spacecraft have flown by and the shape of the solar system itself. Today these 722-kilogram probes, whose instruments mostly are still operating after almost 34 years in space, are helping to rewrite the textbooks about the outer edge of our solar system as they continue to race outward from Earth. Voyager 1, currently 17.4 billion kilometers from Earth, and Voyager 2, 14.2 billion kilometers from Earth, are on their way to becoming the first human-made objects to leave the solar system and enter interstellar space, the medium between stars.

In exclusive interviews with *Eos* and during a 27 April news briefing at NASA headquarters in Washington, D. C., Voyager project scientist Ed Stone and several others who have worked on the project discussed mission highlights and the probes' journeys through the heliosheath. This is the final outer layer of a kind of bubble the Sun creates around itself called the heliosphere, a margin where the solar wind is slowed by the pressure of interstellar gas. All the while, the spacecraft, still responsive to ground commands, are sending back data about the solar wind, the magnetic field carried out by the wind, charged particles, and plasma waves.

Voyager 2 is moving at 3.3 astronomical units (494 million kilometers) per year at 48° out of the ecliptic plane (the plane of the Earth's orbit around the Sun) to the south. Voyager 1, which is speeding along at about 3.6 astronomical units (538.5 million kilometers) per year at 35° out of the ecliptic plane to the north, could in 4–5 years be the first object to cross into interstellar space.

"To be quite honest, nothing has ever been there before. So these [dates] are all estimates," said Stone, who has been project scientist since 1972. Stone, an AGU Fellow, is a professor of physics at the California Institute of Technology (Caltech), Pasadena, and a former director of the NASA Jet Propulsion Laboratory (JPL), which built the Voyagers

NASA/Carla Cioffi

Voyager project scientist Ed Stone.

and continues to operate both probes. Crossing through the heliosphere boundary "will not be exactly what we think," Stone told *Eos*, noting that current models may be only partially helpful in understanding Voyager's environs. He said the boundary will not be a discrete, abrupt interface and that it could be "puzzling" at first as to whether or not Voyager 1 has indeed entered interstellar space.

"Time after time, you have the most to learn when it's not what you expect," Stone said. "On Voyager, it's been very characteristic right from the beginning that the things which we have learned the most about were the things which we had not really thought

about. Or we had thought about them but had not understood the full complexity of what we were thinking."

"We don't know as much as we think we know. And that's the fun thing about being a scientist," Stone said. "If we really knew as much as we thought we knew, we probably would not find this as interesting, because it's always great to be able to confirm what you know and that's important to do. But on the other hand, you are likely to learn more if you find out something different than what you thought you knew or that you didn't even know that you didn't know."

Looking back at the Voyager mission, "the major overall accomplishment was to reveal the diversity of bodies in the solar system, that they are kind of what I call familiar in form but really distinct in detail," Stone told *Eos*. "For instance, there are volcanoes on Io [a moon of Jupiter], but they are not like the volcanoes on Earth. There are geysers erupting on Triton [a moon of Neptune], but they are not like geysers here on Earth." Stone noted that volcanic activity on Io is about 10 times that on Earth even though Io is about the size of our own Moon; active geysers on Triton are erupting at 40° above absolute zero.

Other major mission accomplishments include the flybys of Jupiter and the revelation that the planet's Great Red Spot is a huge, hurricane-like storm system. Flybys of Saturn led to a better understanding of the planet and its rings and moons. When Voyager 1 encountered Saturn, in November 1980, the probe sent back the most detailed images to that date of the planet's complex ring system. Regarding Titan, a moon of Saturn that has a thick methane-nitrogen atmosphere, its atmospheric chemistry could, in some key ways, resemble the Earth before our atmosphere had oxygen. And, to date, Voyager 2 is the only spacecraft to have visited Uranus and Neptune.

Voyager in Context

Stone said the Voyager mission is significant scientifically as well as culturally. He defended the importance of basic research, saying that "the size of the investment is small compared to the return it pays in the long run. But it is a long-term investment. It doesn't happen tomorrow." He also said the mission is "an optimistic activity" that "gives you a sense of a future that can be different than the past. When you learn new things, it changes your view, it changes your understanding."

Stone placed the Voyager mission in context, comparing it in some regards to earlier expeditions such as those of Columbus, Magellan, and Darwin. Stone said part of the reason the Voyager mission resonates with the public is "because you're discovering new things, you're actually going new places, you're seeing new things. It's very much like when people would come back to Europe with all these tales of all this exotic flora and fauna somewhere else. Same idea. Similar in form, different in detail."

At the 27 April NASA briefing, Ann Druyan, creative director of the Voyager Interstellar Message Project that assembled sounds, music, and images for gold-plated copper phonograph records affixed to the spacecraft in the event that alien species find the probes, concurred with Stone's analogy. "The men and women involved in Voyager did something that is absolutely the equal of Magellan or Columbus or any of the great explorers of terrestrial discovery," she said.

Stone's Roots

Stone, born in 1936, said that while growing up in Burlington, Iowa, he wasn't so much interested in science fiction or space but rather was generally interested in understanding how things work. He enjoyed making radios and other instruments using old parts, and he became interested in physics because of the key role played by physicists during World War II. After attending Burlington Junior College, he studied nuclear physics at the University of Chicago beginning in 1956, one year before the launch of Sputnik. In 1961, Stone, by then already an AGU member, flew his thesis experiment on Discover 36, a U.S. Air Force satellite. He came to Caltech, which operates JPL for NASA, in 1964 to help set up a new space research group in physics.

When asked to become the Voyager project scientist, Stone, who by then had launched a number of experiments, did not accept the position immediately. "'Project scientist' could have been a very bureaucratic job, and I wasn't interested in that," he explained. "But I realized that this was going to be a mission of discovery, and it was an opportunity for me to learn a lot. It turned out to be more than I hoped in the way of discovery and the opportunities to help everybody to do their job." In this position, not only has Stone utilized his scientific capabilities, but also his political acumen has helped to guide the project, including helping to convince decision makers to extend the spacecrafts' mission to interstellar space after flying by Neptune.

"I'm very lucky to have a job where I can get up every day and think, 'What am I going to learn today?'" he added.

Some of his colleagues say Stone's dedication often extends far beyond normal business hours. Merav Opher, Voyager guest investigator and assistant professor of astronomy at Boston University, told *Eos* an anecdote about a telephone call with him a few years ago on New Year's Eve. Stone, she said, indicated he might have to break away for about 10 minutes but could pick up the conversation again in the new year. Opher recalled attending her first Voyager team meeting after becoming a Caltech postdoc at JPL in 2001 and seeing Stone sitting at the head of the table and with other scientists in the room. "I felt like I was coming to the *Enterprise* ship of *Star Trek*," she said. "You could tell they'd been analyzing the data, discussing the science, for years."

Looking Ahead

Opher wondered whether a mission similar in shape to Voyager could be launched today or whether people would think that such an extended mission would be "a pipe dream," she told *Eos*.

Druyan expressed similar concerns. "That kind of mythic undertaking that was Voyager, that was Apollo, that was Viking, we have come to feel is somehow beyond us. Our pockets aren't deep enough," she told *Eos*. "And we can't bring ourselves to think in the time scales, the long-term thinking, that's necessary to do things that will not benefit us immediately. That's what scarcity does."

"I think it's not like we'll never do these things again. It's that we have to awaken from the stupor that we've been in and remember that we even have a future. If you look at popular culture, where are the positive predictions of what the future could be?" she added, noting that the Voyager mission "is the confluence of technology, of science, of exploration, and of who we are as a species and what we could possibly be some day if those best angels of our souls, the best part of us, get to win the game."

Stone said that while there may never be another mission like Voyager, which has observed so many things for the first time, NASA still knows how to undertake similarly complex missions such as its missions to Mars. "I've been through budget cycles, and I'm an optimist that eventually," he said, "the importance of doing these things will again be recognized and there will be new opportunities for new things toward the end of the decade."

Stone told *Eos* that his guiding vision during the next decade includes looking at what he refers to as the five frontiers of space: the physical, knowledge, technology, applications, and human frontiers. "What are we going to learn with each mission? What are we going to learn that is going to change our view, that is going to have the same kind of transformative effect as Voyager, where you are not only just learning some things you already probably knew, but you are learning things that you didn't even know that you needed to learn?" he said. "Where are the opportunities? Where is the most likely possibility of stretching our knowledge on those frontiers?"

He added that these frontiers are huge and we will never completely explore all of them. "We have to pick and choose. But it's by doing these things that we create this sense of reaching out beyond, creating a new future, that I think has appeal to people."

—Randy Showstack, Staff Writer