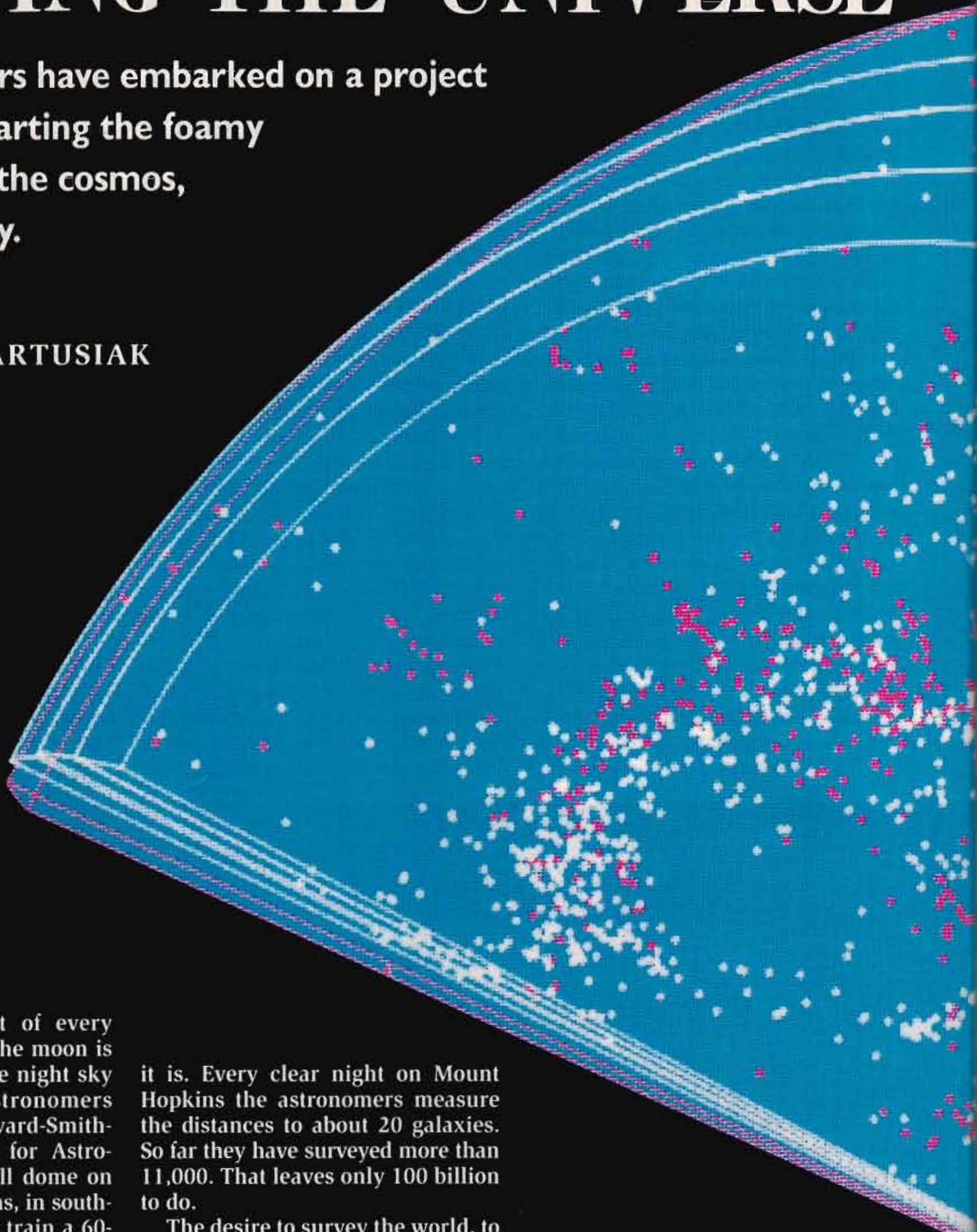
MAPPING THE UNIVERSE

Two astronomers have embarked on a project for the ages: charting the foamy architecture of the cosmos, galaxy by galaxy.

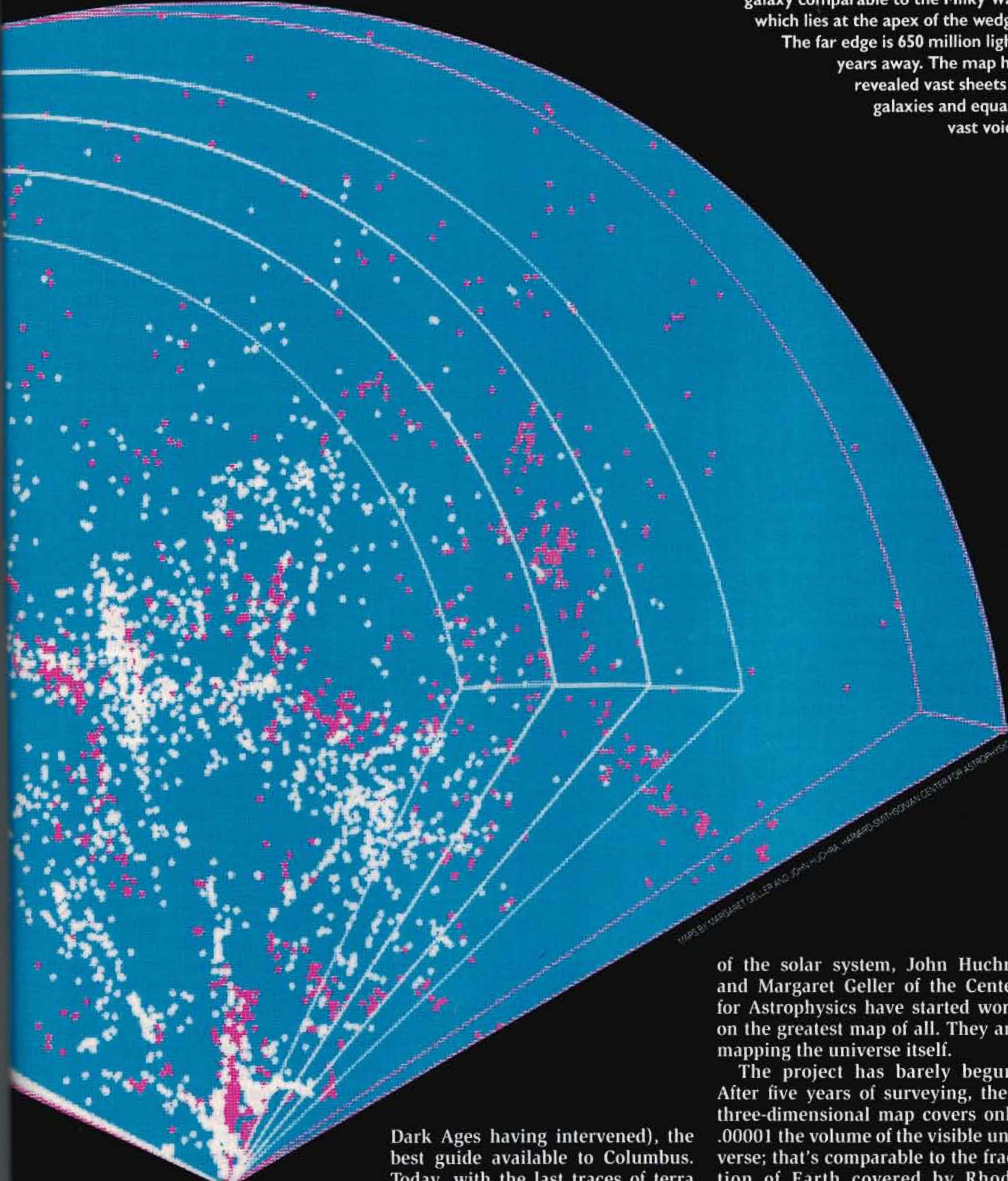
BY MARCIA BARTUSIAK



Two weeks out of every month, when the moon is a sliver and the night sky is darkest, astronomers from the Harvard-Smithsonian Center for Astrophysics repair to a small dome on the side of Mount Hopkins, in southern Arizona. There they train a 60-inch reflecting telescope on distant galaxies. They don't actually look at the galaxies, of course; few astronomers do that anymore. But unlike many of their colleagues, these researchers don't even pause to make pretty pictures. They're primarily concerned with just one of each galaxy's vital statistics: how far away it is. Every clear night on Mount Hopkins the astronomers measure the distances to about 20 galaxies. So far they have surveyed more than 11,000. That leaves only 100 billion to do.

The desire to survey the world, to fix its shapes and sizes and one's own place in it—in short, the desire to make maps—is one of the constants of human nature. Prehistoric humans probably scratched directions to water holes or game trails on bits of bark; but the oldest surviving map of the whole Earth is a clay tablet, carved around 1000 B.C. by a nameless Babylonian, who depicted his world as a disk with Babylon at the center. The mapmaker's art reached its ancient zenith with the Alexandrian mathematician and astronomer Ptolemy, whose sketchy outlines of landmasses and oceans were still, 13 centuries later (the

Each dot in this wedge of universe mapped by Harvard-Smithsonian astronomers is a galaxy comparable to the Milky Way, which lies at the apex of the wedge. The far edge is 650 million light-years away. The map has revealed vast sheets of galaxies and equally vast voids.



MAPS BY MARGARET GELLER AND JOHN HUCHRA, HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS

Dark Ages having intervened), the best guide available to Columbus. Today, with the last traces of terra incognita removed from maps of Earth, and with space probes having poked into nearly every corner of the solar system, John Huchra and Margaret Geller of the Center for Astrophysics have started work on the greatest map of all. They are mapping the universe itself.

The project has barely begun. After five years of surveying, their three-dimensional map covers only .00001 the volume of the visible universe; that's comparable to the fraction of Earth covered by Rhode Island. Yet the map has already caused a stir. Astronomers used to think galaxies were dispersed through space in a uniform mist, and that a map of the universe would therefore be featureless and boring. But Huchra and Geller have discovered vast bubblelike collections of galaxies, huge galaxyless voids, and, just this past year, a thin sheet of galaxies, dubbed the Great Wall, that stretches a half billion light-years from end to end. As the map gets larger, so do the features it reveals. The immense size of these structures has left astronomers as surprised as Columbus was when he set out for India, guided by Ptolemy, and bumped into the New World instead.

The foundation of modern cosmic cartography was laid more than 60 years ago, when Edwin Hubble verified that other galaxies exist—that the spiral patches in the night sky are like our Milky Way rather than part of it, and that these galaxies are flying away from ours as the universe expands. The light waves emitted by the receding galaxies are stretched and thereby nudged toward the red end of the spectrum; the faster the recession, the greater the redshift. Hubble's great discovery was that the fastest galaxies were also the farthest, judging from how faint they were. Thus the distance to a far-off galaxy could be gauged from its redshift. With that, it became theoretically possible to map the three-dimensional distribution of galaxies instead of just their position in the sky.

But neither Hubble nor anyone else chose to do so in a systematic way. One reason was simple prejudice. Although observers noted that some galaxies are gathered into clusters, everyone assumed that over larger distances this clumpiness would be smoothed out, the way waves are smoothed out when you look at them from far above the sea. If the universe was smooth and featureless, there was no point in mapping it.

But there was also a technical obstacle. In the early days redshifts were hard to obtain. Milton Humason, Hubble's colleague and the consummate observer of his era, had to sit for hours at his telescope to record the light spectrum needed to determine the redshift of just one galaxy. So astronomers generally didn't bother; they were content just noting a galaxy's celestial longitude and latitude. Twenty years ago only several hundred redshifts were known.

In the 1970s, though, as observatories replaced light-squandering photographic plates with more efficient electronic detectors, it became possible to take a redshift in half an hour rather than an entire night—and with a modest telescope instead of the 200-inch giant on California's Palomar Mountain. Armed with this new equipment, astronomers started seeing superclusters of galaxy clusters as well as vast voids—regions of space that were nearly empty of galaxies. The most dramatic of these voids, observed in 1981 in the direction of the constellation Boötes, was 300 million light-years across. But many astronomers were still not convinced that these structures were at all common.

"I used to say I was a physicist, which ended the discussion. I once said I was a cosmologist, but I got asked about makeup. Now I say I make maps."

Huchra was one of the skeptics. A few years before the Boötes discovery, he and three colleagues had begun their first redshift survey, mapping some 2,400 galaxies, scattered over a third of the sky out to a distance of 250 million light-years. They detected hints of a spongy cosmic architecture, but the evidence was inconclusive at best.

So inconclusive, in fact, that when Huchra and Geller embarked on a more ambitious and systematic redshift survey in 1985, they had no special interest in mapping the galaxy distribution; they expected it to be smooth. They were more interested in finding out how many galaxies there are in a given volume of space—an old and fundamental question in astronomy. This time they took a representative slice across the sky—a thin pie wedge with Earth at the apex. At the far edge of the slice, 650 million light-years away, were galaxies 6,000 times too faint to be visible to the naked eye. Almost as an aside, Huchra and Geller instructed a French graduate student, Valérie de Lapparent, to construct a map of the survey's redshifts. "We held off plotting the results," recalls Huchra, "because we 'knew' they were going to be smooth."

That summer De Lapparent showed the results to her advisers. Huchra, who was in charge of the observations, did a double take. His first thought was, "How did I screw up?" But the data immediately converted Geller, a theorist and, like Huchra, someone who had been skeptical of reports of extremely large structures in the universe. "I knew John couldn't have fouled up," she says. "The structures were so obvious."

On De Lapparent's map the galaxies weren't scattered randomly; they were congregated along the surface of gigantic, nested bubbles, which Geller likened to a "kitchen-sink-full of soapsuds." Inside the bubbles were equally huge voids. Most noticeable of all was the shape in the center of the plot, which many people mistook for a joke. The shape resembled a stick figure, its torso representing a prominent group of galaxies called the Coma cluster.

With these startling results, and with their newfound interest in cosmic cartography, Huchra and Geller added a title to their résumés. "When people on airplanes ask me what I do, I used to say I was a physicist, which ended the discussion," says Geller. "I once said I was a cosmologist, but they started asking me about makeup, and the title 'astronomer' gets confused with astrologer. Now I say I make maps."

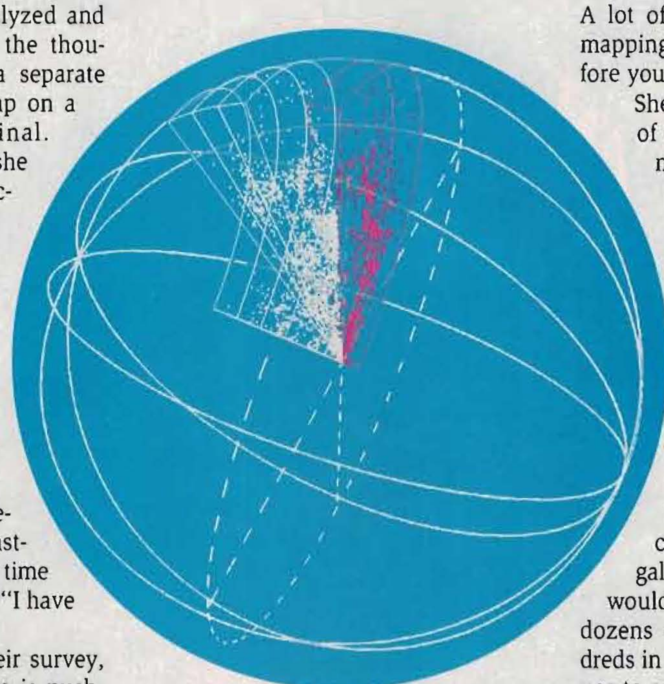
Since 1985 Huchra and Geller have stacked eight more slices onto their first one, opening the original wedge up like a bellows. Each round of the search begins at the Center for Astrophysics at Harvard. In a third-floor room some 20 cardboard boxes are lined up on shelves according to the celestial position of their contents—hundreds of Polaroid shots of galaxies, with vital statistics on each.

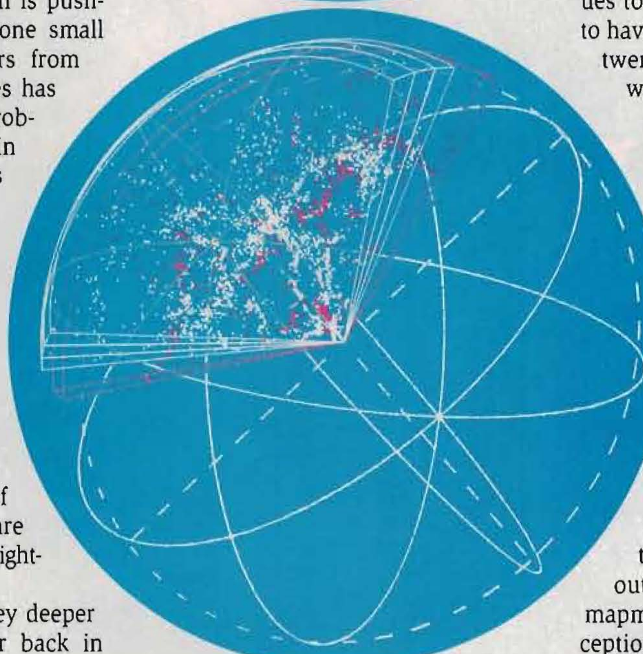
Huchra and Geller send pictures of the targets they've chosen to Arizona, where Harvard-Smithsonian observers Edward Horine and James Peters, as well as Huchra and the occasional graduate student, gauge the galaxies' redshifts. The light from each galaxy is broken down into its component wavelengths by a spectrograph, much the way a prism creates a rainbow out of sunlight. The redshift caused by the galaxy's motion is measured from the shift of well-known spectral lines, such as the wavelengths at which calcium and oxygen emit and absorb light.

The spectroscopic data, collected on computer tape, are sent back to Massachusetts, where they are analyzed and added to the map. Each of the thousands of points represents a separate galaxy. Geller studies the map on a computer graphics terminal. Manipulating eight knobs, she can examine the frothy structures from any angle. The galaxies whiz by as she zooms into the wedge, flying through the voids like a spaceship in hyperdrive, to get a close look at the Great Wall, an unmistakable band running across the screen. "I find the pattern artistically pleasing," says Geller (who once considered a career in design). Her colleague Ron Eastman puts it differently. "Every time I walk by this room," he says, "I have to stop and say, 'Wow!' "

In addition to widening their survey, the Harvard-Smithsonian team is pushing it deeper into space in one small patch. A team of researchers from England and the United States has already tried this approach, probing the universe along two thin cores in opposite directions from Earth, each core extending 5 billion light-years. What they saw was evidence for a series of Great Walls, perhaps arranged in a kind of honeycomb structure. "It's as if we pierced an extremely narrow needle through the universe and hit one wall after another," says team member Alex Szalay of Johns Hopkins. The walls are separated by voids 400 million light-years across.

By pushing their own survey deeper into space—and thus further back in time—Huchra and Geller hope to find some clues as to how such huge structures could have been built. The conventional view is that the walls of galaxies were pulled together by gravity; specifically, by the gravity of "cold dark matter," an unseen form of matter that is thought to make up at least 90 percent of the mass of galaxies and of the universe as a whole. And indeed, the most recent computer simulations of the cold dark matter model have been able to reproduce roughly the walls and voids seen on the cosmic maps.





The cosmic map can be examined from any angle on a computer screen. So far it covers .00001 of the visible universe.

But Geller thinks there is something more going on—something that future maps may reveal. "I often feel we are missing some fundamental element in our attempts to understand this structure," says Geller. "Nobody could imagine plate tectonics without a good map of the Earth. And no one could figure out the precise role of DNA before scientists mapped its arrangement of atoms. A lot of science is really the same as mapping. You have to make a map before you understand."

She and Huchra are three-quarters of the way to their interim goal of measuring and plotting 15,000 redshifts—which, considering that there are billions of galaxies in the universe, is a drop in the bucket. Their funding is far from secure, though, and once they reach the 15,000 mark the leadership in cosmic mapping may pass to other researchers. Astronomers in England, for instance, are working on a fiber-optic array in which each fiber would collect the light from a single galaxy in a cluster; that device would make it possible to measure dozens of redshifts at once and hundreds in one night. "If technology continues to advance, astronomers can expect to have a couple million redshifts within twenty-five years," notes Geller. "That would still be only one-thousandth of the universe's volume, but then it took hundreds of years to map the Earth."

And as Huchra points out, cosmic mapmakers have just now reached the stage where geographers were when the New World was discovered. "Back then there was a lot of theoretical, yet incorrect, knowledge about what the world was like," he says. "Some thought the world might be flat and you could fall off the edge, but the explorers went out and found out what was truly there. Celestial mapmaking is very similar. Our preconceptions of a uniform universe are now shattered—only we never had to worry about falling off the edge." ❑

Marcia Bartusiak wrote about sunspots and the weather in the November issue.