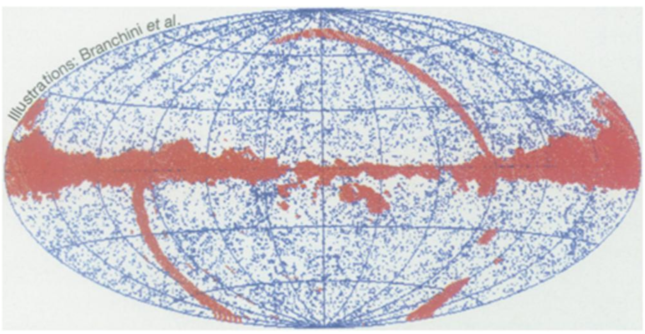
Whole-Sky Catalog

A modest but universal map of the nearby cosmos proves its power

By RON COWEN

With much fanfare, cosmological cartographers last year began work on an unprecedented map of the heavens. When the Sloan Digital Sky Survey is completed in 2002, it will chart the position and distances of 100 million galaxies distributed over one-quarter of the sky (SN: 1/23/99, p. 57).



Dots show location of the roughly 15,500 galaxies in the Point Source Catalog Redshift Survey. Based on observations taken by NASA's Infrared Astronomical Satellite, the survey encompasses 84 percent of the sky and includes galaxies as far away as 700 million light-years. Red regions indicate areas where galaxies were not mapped.

Although it has received little publicity, a small but detailed map of nearly the entire sky has already been pieced together by astronomers. Based on infrared satellite images and bearing the uninspiring name Point Source Catalog Redshift Survey, it is the most extensive three-dimensional map of the local universe ever compiled, asserts Carlos S. Frenk of the University of Durham in England.

Compared with the mammoth undertaking of the Sloan survey, the new map encompasses a paltry 15,500 galaxies. Yet by revealing how these galaxies cluster and allowing astronomers to predict their motion, the PSCz survey (z stands for redshift) is providing a new estimate of the mass of the local universe. The Sloan survey, for all its detail, will not be able to deliver this information.

The new map covers 84 percent of the sky and includes galaxies that lie as far as 700 million light-years from Earth. "When you want to know the motion of a galaxy in the sky"—in what direction it's pulled or pushed by other galaxies or clusters of galaxies and by how much—"you need full-sky coverage," says Enzo Branchini of the Kapteyn Institute in Groningen, the Netherlands, a member of the mapping team.

"You need a spherical region, with our galaxy at the center, to predict the motions of the galaxies in the nearby universe," he explains. "If you miss some part of the sky, then you introduce very big errors when you want to try to model the motion of galaxies on large scales."

Measurements of redshift, the amount by which cosmic expansion shifts light toward longer wavelengths, indicate a galaxy's velocity. Although the redshifts of the galaxies in the PSCz survey were measured in visible light, the galaxies themselves were first identified in infrared observations by a NASA satellite. During its 1983 mission, the Infrared Astronomical Satellite flew above the confounding glow of Earth's atmosphere, enabling it to survey the distant reaches of the cosmos at four mid-infrared wavelengths.

The satellite's observations were crucial, notes Frenk, because infrared light penetrates the veils of dust that often hide the visible light emitted by galaxies. Many regions of the sky, especially those that can only be seen by peering through the dust clouds that cloak our own Milky Way, look empty in visible light but appear chock-full of galaxies in infrared.

"In a visible-light survey, you don't know if you're actually detecting all the galaxies, whereas in the infrared, you've got the complete picture," says Richard G. McMahon of the University of Cambridge in England.

"The immediate interest in producing maps like this one . . . is to increase our knowledge about the structures in our local universe. The data set we have used allowed us to explore regions out to unprecedented distances along almost all directions in the sky," says Branchini.

Branchini displayed the map last August at a cosmology workshop in Garching, Germany. Previous maps constructed from the same infrared data were based on redshift determinations for only about one-third as many galaxies, excluding many of the faintest ones.

The new survey "is much better because it is a denser sample of the local universe," says Marc Davis of the University of California, Berkeley. "It has better statistical properties, less noise, and so will supersede all the older catalogs." Several years ago, he and his colleagues compiled a less detailed sky map based on images from the infrared satellite.

"Other surveys have pushed the exploration out to much larger distances, but they've been restricted to very small patches in the sky," Branchini notes. The Sloan survey "will go much deeper still, and it will cover a very large area, but no survey [now underway] will examine the whole sky."

Frenk and a British team of astronomers led by Will Saunders of the University of Edinburgh in Scotland labored for 5 years to assemble the sky map, using a slew of telescopes in both the Northern and Southern Hemispheres.

Analyses of the PSCz map, says Frenk, are allowing astronomers "to measure some of the most fundamental cosmological parameters that describe our world model." Such measurements can help answer whether the universe will expand forever or ultimately collapse in the Big Crunch.

Like smaller surveys of the nearby universe, the new all-sky map confirms that galaxies are not sprinkled uniformly around the Milky Way. Rather, they are arranged in a cosmic web: large clumps of galaxies interconnected by filamentary structures and separated by vast, nearly empty regions of space.

By revealing the clumpy structure of the nearby universe, the PSCz map enables astronomers to estimate how gravity has helped shape the local universe. The universe has expanded ever since the Big Bang, and this cosmic expansion causes galaxies to recede from each other with a predictable velocity. It's as if all the galaxies occupy positions on a uniformly expanding grid, each galaxy moving at what is called its recession velocity. The cosmos thus is expanding and becoming less and less dense throughout.

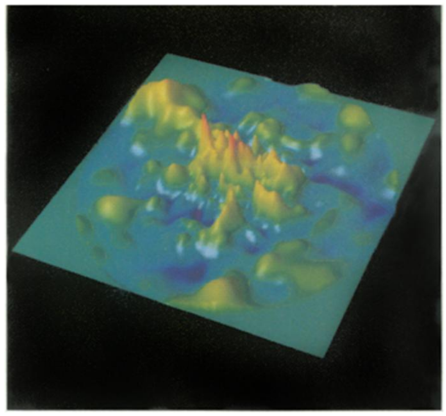
In reality, things are a good deal messier. This simple model does not take the full complexity of gravity into account. As the universe evolved, gravity gathered galaxies into regions of slightly enhanced density, creating larger and larger concentrations of matter. These concentrations exert a small but measurable tug on nearby galaxies. As a result, the velocities of the galaxies deviate slightly from that imparted by cosmic expansion.

From the positions of all the galaxies in the sky map, astronomers can predict how each galaxy should move in response to the gravitational influence of all the others. By comparing these predictions with the measured velocities, they can deduce the amount of both visible and dark matter in our corner of the cosmos.

From this calculation, astronomers can infer the average mass density of the universe, says Frenk. The density determines whether the cosmos will continue to expand indefinitely or whether there's enough material to cause the universe to contract.

The information contained in the PSCz map "provides a remarkable way to measure the mass of the universe," says Davis. In agreement with a slew of other observations, the survey indicates that the universe does not have enough mass to keep from expanding forever. This evidence for a low-density is the survey's most important result, says Branchini.

At the same time, he and his colleagues find no support for a controversial report that a vast number of galaxies in the nearby universe are flowing at high speed across the sky, like a swiftly moving cosmic river (SN: 12/12/92, p. 408). The researchers find instead that the galaxies move much more sluggishly and in a different direction, toward a cluster of galaxies known as the Shapley Concentration. Branchini and his collaborators report the finding in an article posted on the Internet (http://xxx.lanl.gov/abs/astro-ph/9901366).



Three-dimensional map of the density of the local universe, out to a distance of 500 million light-years, as revealed by the new full-sky survey. Earth's home galaxy, the Milky Way, lies at the center. Highest densities are indicated by red and yellow. The map depicts a series of interconnected regions of high density separated by large voids. The most prominent structure is a ridge extending from the Perseus-Pisces supercluster of galaxies, near the center of the map, all the way to the Shapley Concentration of galaxies, located near the top left corner.

In addition, the distribution of galaxies revealed by the map indicates that the Milky Way is moving approximately toward a cluster of galaxies called Hydra-Centaurus at a speed of 620 kilometers per second. This matches the velocity deduced by an independent method based on measurements of the cosmic microwave background, the faint radiation left over from the Big Bang.

"That's an exciting result," says Davis. "It says we think we can see in the galaxy distribution the material that has caused us to move. We can also see how far away [the material] is. Most of it is within 120 million light-years."

In future work, Frenk, Branchini, and their colleagues plan to take a journey back in time. Reconstructing the density, temperature, and other conditions that may have existed during the earliest moments of the universe, they intend to study the evolution of several model universes with the help of a supercomputer. The correct model should reproduce the structure of the present-day cosmos as seen in the sky map.

In the meantime, while astronomers await the cornucopia of results from the Sloan survey, they have a new and complete atlas of the galaxies in our cosmic neighborhood to explore. □