A River Runs Through It?

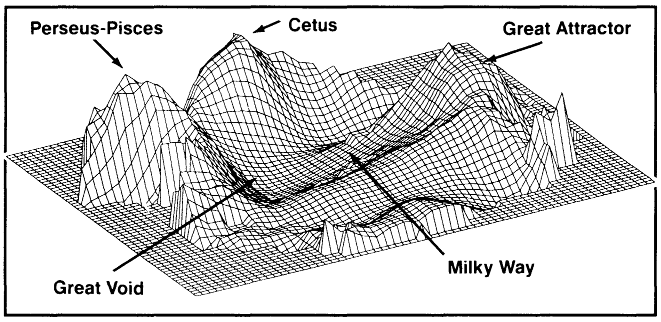
Mapping the flow of the universe

By RON COWEN

The ancient Egyptians thought of the heavens as a steady river along which the sun sailed by day and the moon by night. Cosmologists today see a much bigger and faster river in the sky.

Forget the gentle flow of sweet Afton. Think instead of the mighty Mississippi. If astronomers are right, the Milky Way and thousands of other galaxies are streaming in concert across the heavens at the furious rate of some 375 kilometers per second.

And just as canoeists look at ripples in a river to discern unseen rocks, astronomers identifying patterns in the cosmic flow have begun to use their river sense to map the lumps of matter in the universe — both visible galaxies and the far greater proportion of hidden, dark material.



Dekel, Bertschinger

Hitchhiker's guide to the local universe: Hills and valleys denote regions of high and low mass density.

Using these maps, says Avashai Dekel of Hebrew University in Jerusalem, astronomers are beginning to find the first tentative answers to some of the most fundamental questions about the large-scale structure of our universe. Such questions include: Will the cosmos expand forever, or does it contain so much matter that it will eventually collapse back in on itself? How is dark matter — hidden material that doesn't glow like stars yet still exerts a gravitational tug — distributed in the universe? And how well do the positions of visible galaxies mark the location of this hidden matter?

"We're like old-fashioned cartographers," says Tod R. Lauer of the National Optical Astronomy Observatories in Tucson, Ariz. "As our maps grow, we're beginning to understand more about the universe." And as researchers extend their maps, another puzzle has emerged: Exactly what reference frame should astronomers use to measure the motion of galaxies?

Before the 1970s, astronomers didn't believe galaxies had any large-scale streaming motion other than the velocity associated with the expansion of the universe. But in 1975, Vera C. Rubin and W. Kent Ford of the Carnegie Institution of Washington (D.C.) reported that our galaxy may move at about 700 kilometers per second.

Two years later, a group of balloon-borne instruments seemed to lay to rest the notion that our Milky Way is stationary. The instruments detected a tiny variation in the cosmic background radiation, the glow left over from the Big Bang explosion believed to have given birth to the universe. Many theories require that this radiation be uniform, permeating the cosmos equally in all directions. But across one half of the sky, the radiation appeared to be a few thousandths of a degree hotter than expected, while in the other half it appeared a few thousandths of a degree cooler.

The simplest explanation of the temperature difference, cosmologists reasoned, was that our galaxy moves at a speed of some 600 kilometers per second. Such motion would cause the uniform background radiation to appear slightly hotter over one half of the sky and slightly colder over the other.

In 1986, a group of scientists found evidence that above and beyond this motion, the Milky Way and many other galaxies and galaxy clusters move toward a distant supercluster in the constellations of Hydra and Centaurus. The research team of seven astronomers from seven universities, later dubbed the Seven Samurai, reported that a huge concentration of matter must lie at least 150 million light-years from Earth.

Such a concentration, as massive as 10,000 trillion suns, would supply the gravitational tug needed to account for the large-scale streaming. The researchers, who included Sandra M. Faber of the University of California, Santa Cruz, and Alan Dressler of the Observatories of the Carnegie Institution of Washington in Pasadena, Calif., named that mass the Great Attractor (SN: 4/4/91, p.60).

Since then, other researchers, including Donald Mathewson and his colleagues at the Mt. Stromlo Observatory in Australia, have found evidence for a much wider flow of galaxies — a river in the sky that extends two to three times beyond the Great Attractor. And in separate studies, Jeffrey A. Willick of the Observatories of the Carnegie Institution of Washington and Stéphane Courteau of Cornell University in Ithaca, N.Y., have doubled the width of the river identified by the Seven Samurai. They observed galaxies on the opposite side of the sky from the proposed Great Attractor and found a coherent streaming motion of these galaxies toward the same concentration. Other researchers who have analyzed Mathewson's data, including Faber, dispute the notion that all galaxies move at the same speed across the sky, but they nonetheless find an overall flow in the same direction.

These findings suggest that while the Great Attractor may indeed represent a substantial concentration of mass, a much bigger and more massive source of gravity exists at even greater distances than have been surveyed. Says Dressler: "It's ironic looking back, but the thing that was controversial in 1986 was, How could there be such motions as [the Great Attractor] on such large scales? Now we're being criticized for not thinking big enough."

Mathewson told Science News that based on his latest, unpublished data, even the very distant concentration of mass known as the Shapley concentration — believed to lie about 450 million light-years from our galaxy — isn't far enough away to explain the large-scale streaming motion. Indeed, Mathewson says he is so uncomfortable about the size of the proposed, unmapped mass that he would prefer to believe there is no river at all.

Rather than just go with the flow, other astronomers have converted river maps into maps that reveal the lumps and bumps of mass in the universe. Using data culled by several groups who have surveyed the heavens, Dekel and his colleague Edmund Bertschinger of the Massachusetts Institute of Technology began their study in 1989. Their computer-generated maps rely on a single, simplifying assumption: The pull of gravity alone causes the large-scale streaming of galaxies.

Armed with that assertion, the researchers charted the gravitational landscape in two stages. First they constructed a three-dimensional map of galaxy velocities from the one-dimensional line-of-sight velocities that astronomers actually measure when they observe galaxies receding or approaching the Milky Way.

Using a computer program called POTENT, they then used these galactic velocities to create a hitchhiker's guide to the nearby universe: a topographic map whose hills and valleys reveal relative highs and lows in mass density. Moreover, the maps reveal the presence of *all* mass — visible galaxies and dark matter — within the surveyed region, since both exert a gravitational pull.

In particular, the maps show that the region near the proposed Great Attractor has about twice the density of other regions. Intriguingly, a region of the sky directly opposite the Great Attractor, part of a cluster of galaxies known as Perseus-Pisces, also appears mountainous, revealing that it too has a higher-than-average mass density.

These two mass concentrations pull on galaxies in opposing directions. But Dekel suggests that the Great Attractor wins the tug-of-war, since the region between our galaxy and Perseus-Pisces lacks mass. This "Great Void" leaves little material for Perseus-Pisces to grab onto. Thus, the map dovetails with the unidirectional streaming motion of galaxies indicated by several — though not all — sky surveys.

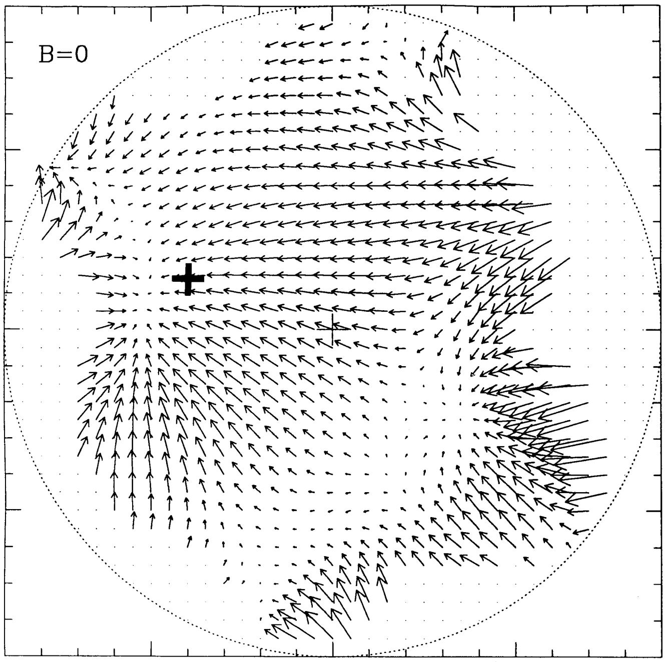
Perhaps most significantly, Dekel and Bertschinger have used their gravity maps to probe the location of mass in the universe. POTENT indicates that the preponderance of mass in the cosmos — assumed to be mostly dark matter — roughly resembles the distribution of visible galaxies. In comparing their topographic map to an all-sky survey of galaxies observed by the Infrared Astronomical Satellite, the researchers found that areas of high mass density do indeed correlate with areas where galaxies cluster.

Faber, who has begun a collaboration with Dekel and Bertschinger to analyze velocity data from some 3,000 galaxies, says more mapping is needed to determine how galaxies and dark matter are distributed. She believes that the majority of dark matter fills the voids between galaxy clusters, along with ordinary visible matter too sparse to be detected.

Dressler adds that it's too soon to say whether there exists a one-to-one, universal correspondence between a given clustering of galaxies and a certain amount of dark matter. It's possible, he notes, that a given concentration of galaxies in different parts of the cosmos may signify different densities of dark matter.

Yet while these uncertainties remain, the power of the POTENT maps goes far beyond their characterization of the nearby universe, Dressler says. "If I can conclude that every time there's a swell in the local galaxy distribution there's a corresponding swell in the underlying mass distribution, then I can confidently use the distribution of [more distant] galaxies to get a fair idea of the mass distribution in the universe at large."

In attempting to figure out whether the universe is open or closed (shorthand for deciding if the cosmos will expand forever or eventually collapse), astronomers invoke a parameter called omega, defined as the ratio of the true average density of the universe to the density needed to just barely close the cosmos. POTENT indicates that omega is no less than 0.3 and could indeed have a value of 1, Dekel told Science News.



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Velocity map, centered on the Milky Way, depicts a river of galaxy clusters. Perseus-Pisces is at bottom right, Great Attractor is marked by crosshair at left.

That preliminary finding has special significance, because an omega of 1 depicts a universe poised between eternal expansion and eventual contraction, a value predicted by some models of the Big Bang. The problem all along has been that a universe with an omega of 1 contains lots of dark matter — about 100 times as much as that found in the visible universe. Before Dekel and Bertschinger began their study, there was scant evidence that so much dark matter existed in the universe. Now the gravity maps indicate a high proportion of dark matter.

"The pieces of the puzzle are beginning to fit together," says Dekel of the unpublished work.

Other questions, equally fascinating, remain — many of them cast in a new light by recent studies. Consider that age-old question, What is the absolute rest frame of the universe? That is, relative to what should all the velocities in the cosmos be measured? No mere philosophical musing, that query goes right to the nub of a basic cosmological principle: The universe should appear identical, on a large scale, no matter in what direction an observer looks.

Since the 1970s, astronomers have believed they had the ultimate reference frame. If the Milky Way and other galaxies are streaming across the heavens, they move relative to the cosmic background radiation, researchers have assumed. In other words, if galaxies form a river, the shoreline is the diffuse afterglow left over from the birth of the universe.

But the results of a new sky survey might call that key assumption into question. Three years ago, Lauer and Marc Postman of the Space Telescope Science Institute in Baltimore set out to examine in greater detail the notion that a Great Attractor or some other concentration of mass was tugging on galaxies in the so-called local group of galaxies, which includes the Milky Way. They reasoned that if a nearby mass concentration were responsible for the local flow of galaxies, then galaxies that reside more than three times as far away would experience little or no gravitational pull. These distant galaxies, unlike the Milky Way and its neighbors, would appear at rest with respect to the cosmic background radiation.

But in analyzing their survey, which examined the brightest galaxy in each of 120 distant galactic groupings called Abell clusters, Lauer and Postman noticed something very curious. Researchers have had evidence since the 1970s that the most luminous galaxy in each Abell cluster has the same intrinsic brightness—as though every bright galaxy were a light bulb with the same wattage.

Nonetheless, some of the bright galaxies appear dimmer than others, because some clusters lie farther from Earth: Brightness declines in inverse proportion to the square of the distance. But even after the astronomers accounted for the different distances, the galaxies still did not appear equally bright, Lauer and Postman reported in September at a cosmology conference in Milan, Italy.

That finding didn't surprise them, however, since the motion of our own galaxy—toward some of the Abell clusters and away from others – makes it appear that some of the clusters are closer to us, and some farther away, than they actually are. Recalibrating the true distance to each Abell cluster, one would find that the galaxies indeed have equal brightness.

But a problem arose when the astronomers calculated what our galaxy's velocity should be in order for the luminous galaxies in the Abell clusters to have identical brightness. That velocity – toward the Orion constellation – doesn't match in speed or in direction the velocity that researchers assume our galaxy must have to explain a familiar pattern in the cosmic background radiation.

The researchers propose two ways to explain their results. They emphasize that they haven't chosen one model over the other, but they add that both theories have some startling consequences.

In one model proposed by Lauer and Postman, the velocity of the Milky Way simply does *not* match the velocity that astronomers insist our galaxy should have for the cosmic background radiation to look identical in all directions. If our galaxy doesn't move at some 600 kilometers per second along a prescribed path in space toward the constellation Hydra, then the tiny variation in the temperature of the background radiation from one half of the sky to the other is no mere artifact of motion.

Instead, that unusual radiation pattern, seen so clearly by the Earth-orbiting Cosmic Microwave Background Explorer (COBE), could represent a bizarre brushstroke painted on the universe soon after the Big Bang. And rather than embodying the ideal of symmetry, the cosmos would be hopelessly lopsided. In one direction, the cosmos would appear hotter, with a slightly higher temperature for the microwave background radiation, and in the opposite direction, cooler. In this model, an explorer would find that the cosmos does have a different appearance along different lines of sight.

The model would also abolish the notion of a river of streaming galaxies, says Mathewson, eliminating the need for some Supergreat Attractor that provides the tug for an enormous flow of galaxies. While Postman and Lauer presented their data without taking sides, Mathewson has adopted the heretical view that the cosmic background radiation does not provide an absolute reference frame with which to measure velocities. And since it's only relative to the microwave background that galaxies appear to flow like a river, maybe, says Mathewson, nothing is moving at all.

Alternatively, the universe might keep its reputation as an absolutely symmetrical structure that looks the same in all directions. In that case, Lauer and Postman assert, the galaxies in the Abell clusters must themselves be moving relative to the cosmic background radiation.

Such motion could explain equally well why some of the bright Abell galaxies that the researchers surveyed appear to glow more brightly than others. But that motion also suggests that one or several huge collections of matter, well beyond the location of the Great Attractor and residing somewhere outside the surveyed region, is pulling on the Abell clusters.

Indeed, the Great Attractor seems downright puny compared to this vast proposed blob. The researchers estimate that the concentration of matter could be as great as 100,000 times the mass of our galaxy and lies at least 300 million light-years from Earth.

Faber notes that the immensity of such a structure, both in size and mass, seems at odds with high-resolution studies of fluctuations in the cosmic background radiation recently conducted in Antarctica. Such fluctuations represent the seeds of cosmic structure, and the South Pole studies don't find evidence for such large-scale lumpiness. The concentration of mass required to tug a big river of galaxies doesn't yet contradict COBE results, since the craft examines lumpiness – fluctuations in background radiation – on much larger angular scales than the Antarctic studies (SN: 5/2/92, p.292). But trouble may loom on the horizon.

What if the river of galaxies is even bigger than current surveys suggest? A bigger river implies that an even bigger concentration of mass lies farther out in the heavens. COBE might be hard-pressed to square such large-scale lumpiness with its results, notes Faber. But COBE investigator George F. Smoot of the University of California, Berkeley, says he believes further surveys of the type conducted by Lauer and Postman will show that more distant galaxies aren't part of a river; they don't move with respect to the cosmic background radiation.

Smoot hopes that as researchers look just slightly farther out in the cosmos, they will discover the hulking mass responsible for the motion of galaxies nearer our own galactic neighborhood. Galaxies residing just beyond that mass, he notes, would experience a gravitational tug back toward the dense region rather than stream ahead. And at even greater distances from the mass, galaxies would have little motion – backwards or forwards – other than the velocity caused by the expansion of the universe.

"I believe that when [astronomers] look on bigger and bigger scales, then a lot of these motions will damp down," says Smoot.

C. Winter

The far-reaching implications of the Lauer-Postman study make the survey "a very, very important piece of work," says cosmologist Jeremiah P. Ostriker of Princeton University in New Jersey. He notes that very few models for the evolution of the universe could account for the proposed large-scale mass concentrations that researchers say the Lauer-Postman study hints at. But one such model, says Ostriker, assumes that dark matter in the universe is composed only of ordinary matter rather than the exotic, unknown types of material that theorists often invoke. He and a Princeton colleague, N.Y. Gnedin, detail some of their work in the Nov. 20 ASTROPHYSICAL JOURNAL.

James E. Gunn of Princeton takes another view. He maintains that a variation of a popular model for the evolution of the universe, called inflation, could explain how the leftover radiation might really produce an asymmetrical pattern. In the standard inflation model, the universe expands or inflates rapidly, and small-scale lumps in the cosmos are smoothed out. Every piece of the universe, on a big enough scale, looks the same.

But if inflation were cut short, then some of the lumpiness might remain, Gunn suggests. If some kind of "tilt" were present in the radiation pattern at the birth of the universe, says Gunn, an incomplete inflation might preserve a hint of that initial asymmetry. He likens incomplete inflation to an earthquake that is powerful enough to demolish a mountain, yet that leaves behind a sloping pile of rubble that hints at the original lumpy structure.

"Whenever we look at the universe, we're surprised at what we see," notes Gunn. But he and other scientists look forward to even larger maps of the sky that can more fully reveal structure in the cosmic river – if the river truly exists. □