Mapping the River in the Sky

From one side of the sky to the other, galaxies are flowing, pulled by unseen masses. But those masses don't always show up where cosmologists expect them to

In Greek, Chinese, and certain Native American myths, the Milky Way is a great river flowing across the sky. The myths are only partly wrong. The river is there all right, cosmologists now say, but the Milky Way is just part of it, lying midstream in a much greater river that extends for more than 100 million light-years in either direction. The flow—a motion over and above the general expansion of the universe—includes thousands of galaxies, moving together at about 425 kilometers a second. A river indeed.

The scale of this cosmic river became apparent only recently, when Jeffrey Willick of the Carnegie Observatories and Stéphane Courteau of Cornell University found that astronomers had seen only half of it. Earlier observers had been mapping the flow of galaxies in one part of the sky, toward a distant "Great Attractor" and beyond. But Willick and Courteau, working independently, found that galaxies in the opposite side of the sky are moving too, taking part in the same overall flow; they are the upstream part of the same river. "Everything is moving," says cosmologist Sandra Faber of the Lick Observatories, changing the metaphor, "like a flock of birds."

Cosmologists have mapped the flow as far as they can measure galaxies' motions, and they still don't know its full extent. But already the flow has given cosmologists something they've never had before: a way to map the universe's mass. Much of that mass is "dark" matter, matter that isn't in stars and galaxies and doesn't shine. The only way to find it is by its gravitational pull—the same pull to which the flow is most likely responding. But what the flow seems to be saying about how that mass is distributed has cosmologists in a bind.

Cosmologists would like to assume that dark matter is roughly where the galaxies are—indeed, dark matter is thought to have been the scaffolding on which galaxies formed. In one part of the river, a comparison of the flow and the clumpy pattern of galaxies seems to bear out that assumption. But in the other, the assumption breaks down. The galaxies just don't seem to trace the mass that's pulling the river along.

Found: A Universe in Balance?

The great river of galaxies flowing from one side of the sky to the other has given cosmologists a way to trace the distribution of the universe's mostly invisible mass—with unexpected results (see main text). But besides hinting at where the mass is, the large-scale flows offer insight into how much is out there. And this time around the theorists are getting the answer they expected: tentative evidence that the universe—or at least our corner of it—contains perhaps 100 times more mass than meets the eye.

Cosmologists express the total amount of mass in the universe in terms of omega: the ratio between the actual density of the universe and the density needed to stop the outward expansion. The most complete version of the big bang theory for the universe's origin, the inflationary model, firmly predicts an omega of 1—a universe on the hairy edge between expanding forever and coming to a halt.

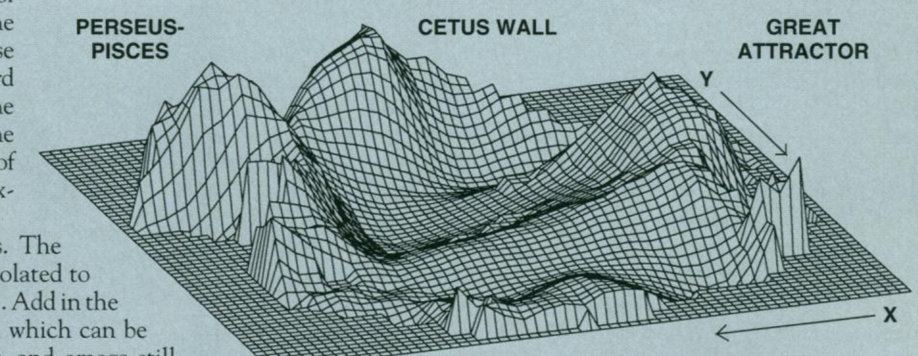
But all that mass has eluded observers. The observable galaxies all added up and extrapolated to the rest of the universe equal an omega of .01. Add in the "dark" matter around galaxies and clusters, which can be calculated from its effect on their motions, and omega still equals only .1. It would be the usual standoff between theorists and observers, if not for the large-scale flows.

In unpublished work, the same team of astronomers that used the flows as a probe of how mass is distributed have joined forces with two other researchers to calculate just how much mass is needed to drive them. Edmund Bertschinger of the Massachusetts Institute of Technology and Avishai Dekel of the Hebrew University of Jerusalem, working with a computer program they call POTENT, had converted all the peculiar velocity observations into a single map of the hills and valleys in the local gravitational terrain. When the researchers calculated the amount of mass implied by that terrain and extrapolated it to the rest of the universe, they got a result that is "consistent" with an omega of 1, according to Bertschinger.

The finding is so hedged with assumptions and uncertainties that cosmologists—including the researchers themselves—take it with a grain of salt. "I don't think there's a clear-cut answer," says Stéphane Courteau of Cornell University. And if omega is truly 1, cosmologists would have a nice confirmation of theory but a new puzzle. If the universe is as old as the oldest stars indicate, a high omega—a universe with the gravitational brakes on hard—should mean a slow expansion rate. But observers have recently been coming up with a high expansion rate. Either the universe is younger than its oldest stars—an uncomfortable prospect—or something is amiss in the expansion or density observations.

"The high omega is making people uncomfortable," says Michael Strauss of the Institute for Advanced Study. "It's not true that we have a coherent picture. One fraction of the pieces fits together. But when you look at another fraction, they fit together too"—into a different picture.

–A.F.



DEKEL AND BERTSCHINGER

Mighty mountains. A gravitational landscape calculated from the flows implies a dense universe.

The inconsistency might be the fault of either the flow measurements or the galaxy maps. But the problem could also lie in theorists' assumption of a simple universe: Maybe galaxies reliably trace dark matter in one part of the universe and not in another. "I'm not sure where the problem is," says Martha Haynes of Cornell University, who has been mapping the inconsistent part of the universe for the past 10 years. The maps are "the state of the art. But maybe if we think we can get answers in the first 3 days, we're underestimating the universe."

A quick answer seems too much to expect in any case, since the problem took more than 15 years to develop. Until the mid-1970s, all the galaxies in our cosmic neighborhood were thought to be fairly still, their only motion following the uniform outward expansion of the universe. But in 1976, Vera Rubin and Kent Ford of the Carnegie Institution found that the local cluster of galaxies—which includes our own Milky Way and a few dozen others—is moving through space at 700 kilometers per second, more or less toward a distant collection of galaxy clusters (a supercluster) in the constellations Hydra and Centaurus.

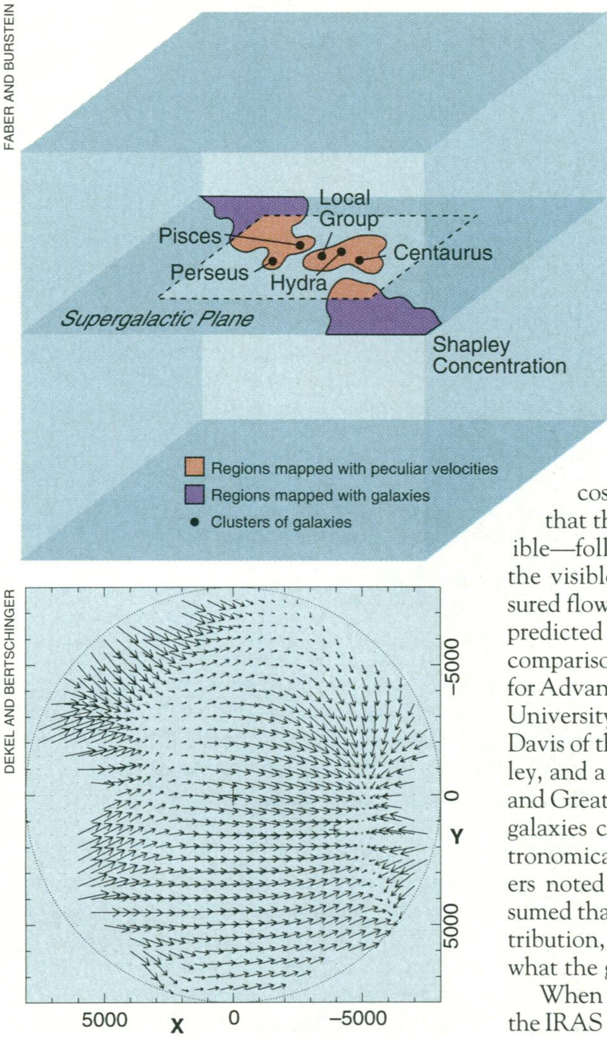
This Rubin-Ford effect was controversial; peculiar velocities are notoriously hard to measure. Peculiar velocity is what's left when you subtract a galaxy's velocity relative to Earth (determined from its red shift) with the velocity it should have due to the cosmic expansion alone. But the velocity a galaxy should have from expansion is proportional to its distance. And measurements of distance are at best indirect. Rubin and Ford assumed that the fainter a galaxy, the greater its distance—a measure with an unavoidably large error.

But 10 years later Rubin and Ford were at least partly vindicated by a group of seven observers from seven universities, called the Seven Samurai. The Samurai (Faber among them) used a distance measure based on tortuous but more trustworthy reasoning: The faster the stars in an elliptical galaxy move, the more massive and intrinsically bright it is. A galaxy's apparent brightness in the telescope, compared to its apparent brightness, could thus reveal its distance. Using that distance measure, the Samurai found that not just the local cluster but many neighboring clusters are all moving toward Hydra-Centaurus, though more slowly than Rubin and Ford had claimed—about 400 kilometers per second. They concluded that a great, unmapped concentration of matter, which they called the Great Attractor, must lie somewhere beyond Hydra-Centaurus, dragging all the local galaxy clusters toward it.

The Great Attractor isn't the end of the story, however, as Donald Mathewson and his colleagues from the Mount Stromlo Observatory in Australia reported a year ago.

FABER AND BURSTEIN

DEKEL AND BERTSCHINGER



All is flux. A locator map *(top)* shows the superclusters taking part in the overall flow *(above)*, which extends from Perseus-Pisces at the upper left to the Great Attractor at the right. Distances are given in terms of cosmic expansion rate in kilometers per second.

The Australian group found that galaxies beyond the Great Attractor are actually moving in the same direction as the galaxies this side of it: The Great Attractor itself seems to be moving downstream. And now observers are tracing the river upstream as well. Courteau and Willick found that the supercluster of galaxies in Perseus and Pisces, on the opposite side of the sky from Hydra-Centaurus and the Great Attractor, is part of the same flow. Galaxies form a single river, running clear across the sky.

So what is pulling the flow? It's headed straight toward an especially thick concentration of clusters beyond Hydra-Centaurus, called the Shapley concentration. To confirm whether the Shapley concentration and the dark matter associated with it is the true attractor, astronomers will have to look beyond to find what they elegantly call the back-side infall—the area where the flow stops, then reverses. But some cosmologists suspect that searching for a single great mass concentration isn't the right way to approach the problem. Rather, the flow is probably shaped by the overall distribution of mass in this corner of the universe. Says one of the Seven Samurai, Alan Dressler of the Carnegie Observatories, "I begin to believe—no, I definitely believe—that looking for a single lump is not the way to approach the problem. Maybe the Shapley is pulling us. But a lot of other big things are pulling us too."

If so, the large-scale flow allows cosmologists to test their assumption that those masses—though largely invisible—follow the same patchy distribution as the visible galaxies. In that case, the measured flows should precisely match the flows predicted from visible mass. To get a point of comparison, Michael Strauss of the Institute for Advanced Study, Amos Yahil of the State University of New York at Stony Brook, Marc Davis of the University of California, Berkeley, and a group of researchers from Canada and Great Britain analyzed an all-sky map of galaxies compiled by NASA's Infrared Astronomical Satellite (IRAS). The researchers noted how galaxies are distributed, assumed that dark matter follows the same distribution, added in gravity, and predicted what the galaxies' velocities should be.

When the peculiar velocity mappers and the IRAS team compared their maps, they got a puzzling result. The maps of observed and predicted velocities do match in one direction, toward the Great Attractor. But in the other direction, toward Perseus-Pisces, the IRAS map suggests that galaxy clusters should be streaming away from Earth—the opposite of what Courteau and Willick observed. "[The maps] disagree in Perseus-Pisces," says Strauss, "and no matter what we do we cannot reproduce the [observed] flow toward us."

The culprits proposed for the discrepancy outnumber the cosmologists offering them. Something might be amiss in the peculiar velocities—in particular, in the distance measurements that are their underpinning. "Anything having to do with [cosmological] distances," says cosmologist Edmund Bertschinger of the Massachusetts Institute of Technology, "is a can of worms." For example, the relationship of galaxy brightness, mass, and star velocities on which the flow measurements are based may vary depending on whether a particular galaxy lives in a dense, turbulent neighborhood or a lonely, quiet one. If the relationship does vary, says Faber, "we throw the [peculiar velocities] data in the trash can and walk away."

Or the IRAS maps of galaxy distributions might be at fault. They cover a volume three or four times larger than that of the flows themselves—too small to encompass all the masses that might be affecting the flows. Nor do they necessarily give an accurate picture of where the galaxies are. "One thing I'm sure of," Bertschinger says, "IRAS galaxies don't trace the mass." Galaxies bright enough in infrared radiation to register on IRAS's sensors are usually young, dusty spirals, and they may not be a good representative of how all galaxies are distributed.

But if both maps are right—and after all they do match in half the sky—then maybe galaxies trace the dark matter only in some parts of the universe and not in others. Some researchers are uncomfortable with such inconsistency. "Why should the universe be that complicated?" asks Davis. But others think it wouldn't be so outlandish. "Maybe galaxy formation is a touch-and-go situation," speculates Dressler, "and things I don't understand could get me twice as many galaxies. Maybe the foam [i.e., the light] isn't directly proportional to the height of the wave [the mass density]. Maybe a little extra sloshing puts twice as much foam on the wave. It's not ridiculous."

Only more data can tell whether that's a real possibility—or whether the bind in which cosmologists seem to find themselves is just an artifact of incomplete maps. So the map makers are pushing onward—Davis' team trying to predict the velocities of fainter and farther galaxies on the IRAS map, Haynes and Courteau analyzing more peculiar velocities in Perseus-Pisces, Willick measuring peculiar velocities at much greater distances, and Dressler reanalyzing known peculiar velocities to test a new distance measure. Until the river and the landscape through which it flows are better known, Faber urges, "don't come to any conclusions about this stuff."

–Ann Finkbeiner

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MEETING BRIEFS

The Wide World of Geography Turns in Washington

Geographers from 82 countries convened on 9 to 14 August in Washington, D.C. for the 27th International Geographical Congress. The 2700 participants–double the attendance of the previous congress, held in Sydney, Australia, in 1988–explored their field's full compass, from malnutrition in the ancient world to modern environmental crises.

Tales From the Burial Mound

Dead men tell no tales, but written in their bones are stories of the foods they ate, the diseases they bore, the physical stresses they endured. And sometimes the tales told by these bony remains differ significantly from those in the history texts.

At the geography congress this month, 500 years after Columbus' voyage to the New World, archeologists painted a picture of the lives of Pre-Columbian Indians that clashes with popular conceptions of a happy, healthy population in a rural utopia. In fact, researchers now know, many of the New World's original inhabitants led settled, communal lives as maize farmers. And their bones, University of Florida biological anthropologist George Armelagos told his audience, show that with this agricultural lifestyle came malnutrition and a bumper crop of ills ranging from iron-deficiency anemia to bacterial infections.

MARK C. GRIFFIN, COURTESY OF CLARK SPENCER LARSEN

The eyes have it. Perforations in the eye sockets reflect porotic hyperostosis, a pathology resulting from iron-deficiency anemia.

Armelagos based his contention on an analysis of bones from 595 individuals at the Dickson Mounds burial site in Central Illinois. During the 300-year-long Pre-Columbian agricultural period, Armelagos says, the bones reveal a fourfold increase in iron-deficiency anemia. The tell-tale sign, he says, is an expansion of red blood cell-producing skeletal regions, a pathology known as porotic hyperostosis, dramatically evident as perforations in the eye sockets of skulls. The obvious culprit, says Armelagos, is maize, an iron- and protein-poor, starch-rich crop that constituted up to 50% of the diet of some Indians. Maize decreases iron absorption, he says, and it is "notoriously poor" in zinc, a deficiency that was also evident in chemical analyses of the bones.

Poor nutrition in turn made the population vulnerable to bacterial diseases that also left their signatures on the skeletons Armelagos examined, and the frequency of disease lesions was highest on skeletons with the lowest levels of zinc. Treponemal infections—responsible for skin diseases and nonvenereal syphilis among the Indians—increased from 20% to 73% during the agricultural period.

But is agriculture solely to blame for this sorry picture? Evidence gathered throughout the Americas by Armelagos, Alan Goodman of Hampshire College, and Jerome Rose of the University of Arkansas indicates that agricultural Indians did hunt and gather a variety of foods. They had to rely so heavily on maize, the investigators theorized, because they traded away their bounty to richer neighbors for status symbols such as copper ear thimbles, seashell necklaces, and obsidian arrowheads. "Archeologists are leery of talking of notions of exploitation [between different tribes of Indians]," says Armelagos, "but trade was not equitable."

Not all archeologists agree that these ills can be laid at the door of trade. "People know what they need in terms of diet," counters University of Wisconsin geographer William Denevan, who thinks large Indian populations probably depleted local game rather than traded it. "To give it away or trade it doesn't make sense." Biological anthropologist Clark Spencer Larsen of Purdue University, who used isotopic analysis and tooth cavities to document the adoption and increased consumption of sugar-rich maize, thinks both the rise in trade and the fall in dietary diversity were critical in determining the Indian diet.

But this may be one issue the bones can't settle. After all, says Larsen, bones are "more like incomplete diaries than epic novels. They don't tell the whole story."

–Dawn Levy

Grass-Root Greens in the Former Soviet Union

The dissolution of the Soviet government lifted the veil on a mind-numbing environmental horror story with multiple chapters: nine less serious nuclear power plant accidents before Chernobyl, the draining of the Aral Sea for irrigation, and countless other messes. Even as information began flowing more freely, however, the power of government to try to clean up environmental disasters has waned, said geographer Philip Pryde of San Diego State University at the geography conference. But Pryde and other geographers reported some good news: Private environmental activists, it seems, are filling some of the void.

Pryde, who wrote *Environmental Management in the Soviet Union* and recently returned