# Astronomers Go Up Against the Great Wall

*The discovery of this huge structure could undermine "cold dark matter" theory of galaxy formation; but what is the alternative?*

FOR MORE THAN A DECADE NOW, astronomers have been haunted by a sense that the universe is controlled by forces they don't understand. And now comes a striking new confirmation: "The Great Wall."

As Margaret J. Geller and John P. Huchra of the Harvard-Smithsonian Center for Astrophysics describe it in this week's cover article in *Science* (page 897), the Great Wall is a system of thousands of galaxies arrayed across the cosmos in the form of a vast, crumpled membrane. With a width of at least 500 million light-years, it is quite simply the largest coherent structure ever seen in the universe—and Geller and Huchra say they have not even located its edges yet. It is far too large and too massive to have formed by the mutual gravitational attraction of its member galaxies. And it may well be too vast to have formed even under the gravitational influence of the "dark matter," the invisible haze that seems to permeate the galaxies like a kind of cosmic ectoplasm.

"My view is that there is something fundamentally wrong in our approach to understanding such large-scale structure—some key piece of the puzzle that we're missing," says Geller.

"This is the most serious challenge ever posed" to standard theories of galaxy formation, agrees University of California, Berkeley, astronomer Marc Davis, another leading researcher in this area.

What makes the Great Wall and other recently discovered structures such a quandary is that they are *so* irregular. And yet astronomers know that the universe came out of the Big Bang in a state of remarkable uniformity: the 2.7 K cosmic background radiation, the afterglow of the Big Bang, varies from point to point across the sky by less than one part in 100,000. In the 10 or 20 billion years since then, of course, gravity has caused the galaxies to clump up into a variety of clusters and superclusters. But astronomers have always thought that if they could only map the galaxies over a large enough volume, the large-scale distribution of matter still ought to be uniform.

Except that so far, it hasn't been. The further out observers look, the bigger the structures they find. In late 1981, to take a notable example, a team of astronomers probing the distribution of galaxies in the constellation Boötes came across a gap nearly 100 million light-years across. Immediately dubbed "the Hole in Space," it was a structure far larger than anyone had ever seen and seemed to defy explanation.

And then in January 1986, Geller and Huchra published the first fruits of their own collaboration. Their idea was to map the distribution of all galaxies brighter than a certain cutoff value, using cosmic redshifts to measure each galaxy's distance. This would then allow them to construct a three-dimensional map of the galaxies' distribution out to a distance of roughly 500 million light-years, thus achieving a much more complete view of our corner of the universe than ever before.

They expected to see the hoped-for large-scale uniformity, with the clusters and superclusters showing up as denser clumps amid a relatively diffuse background of galaxies. Yet their first map, a "slice of the universe" some 135° wide by 6° thick, showed nothing of the kind. Instead of being spread at random, the galaxies appeared to line the walls of "bubbles" as empty as the Boötes void. The map looked like a slice through soap suds.

Geller still marvels at it. "What's striking is how incredibly *thin* these [walls] are," she says. How could a universe that started out so smooth have brought forth structures so big and sharp?

Until recently, the theorists' standard answer was to point to the dark matter. Known only from its gravitational effects on the visible galaxies, the dark matter is generally thought to consist of swarms of exotic elementary particles left over from the Big Bang. But whatever it is, it seems to make up at least 90% of the mass of the universe. Moreover, calculations show that the dark matter would have collapsed into ridges and peaks of density much more quickly than ordinary matter. These concentrations of dark matter could then have pulled in ordinary matter to form galaxies and clusters like flecks of foam upon the wavetops.

With the additional assumption that the dark matter particles are "cold"—that is, that they came out of the Big Bang moving relatively slowly—astronomers have been remarkably successful at explaining the sizes and distribution of the galaxies. Extensive computer simulations of cold dark matter dynamics in an expanding universe have even reproduced the same kind of bubbly, cellular structure found by Geller and Huchra on that first map. The cold dark matter model has accordingly become the standard against which others are judged.

Except that now it is in trouble. Since publishing their first slice of the universe, Geller and Huchra have followed up with three more. In each case, they find the same irregular line of galaxies running roughly perpendicular to our line of sight. The obvious conclusion is that each slice was cutting through the same structure at different points. And if so, says Huchra, "that's perverse": even something as massive as the dark matter has trouble producing a structure that big.

So is the cold dark matter model dead?

Perhaps. Berkeley's Davis thinks so: he is trying to formulate a new model in which dark matter plays a considerably less important role in galaxy formation. Other theorists are exploring exotica such as vast, supermassive cosmic strings.


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**Galaxy mappers.** *Geller and Huchra think something's missing in large-scale structure theories.*

Or perhaps not. Oxford University's George Efstathiou thinks that the cold dark matter model can be salvaged with only minor changes. For example, he says, the first galaxies to form might have somehow enhanced the formation of neighboring galaxies, thus producing much stronger clustering patterns than one would naively expect. The assumption is admittedly ad hoc, he says, but "it's very premature to say, 'Let's rule out cold dark matter.' "

And so it goes. About all one can say at this point is that explaining the Great Wall will not be easy.

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