the model Jupiter, Busse reasoned, then the heat should flow the wrong way too. So, instead of heating the interior, he cooled it, setting up convection of the model's fluid layers.

Busse originally found that Jupiter's rapid rotation organizes spinning vortices like Earth's highs and lows into a ring at a single latitude. But Jupiter's fluid "atmosphere" is so much deeper than Earth's that the vortices can extend deep into the planet or even through it to appear in the other hemisphere.

Olson and Manneville took Busse's "reverse" model Jupiter another step toward the real planet. They cooled the core more intensely, until the model's convection was more vigorous than Busse's had been or than computers can yet simulate mathematically. The columnar vortices persisted, stabilized by the planet's rotation the way spinning steadies a gyroscope, but they broke from their circular pattern to wander chaotically. Theoreticians have long wondered whether these vortices would feed energy into globe-girdling jets, as regions of high and low pressure do on Earth. That's just what happened in Olson and Manneville's model, and the jets formed the familiar Jovian banding.

Such experiments and the Galileo data support the contention that Jupiter's banded wind pattern is linked to the deep interior, but they don't explain the connection in detail. Understanding exactly how deep heat spawns the winds will be a focus of the 2-year mission of the Galileo orbiter, which will be returning its first images of Jupiter's cloud tops next month. Now that they have gotten under Jupiter's skin, scientists hope to divine the inner workings of the planet by stepping back and watching.

–Richard A. Kerr

DISTANT UNIVERSE

Precocious Structures Found

To astronomers, the story of how structures formed in the universe is like a movie with most of the frames missing. They can view at least some of the first scene, 15 billion years ago, in the cosmic microwave background, which retains an imprint of the universe's primordial fluctuations in density. And they know the denouement in today's universe: great clusters, filaments, and walls of galaxies. Because of the difficulty of surveying galaxies billions of light-years away, however, the period in between is largely a blank. Now their best look yet at the missing footage has left them more puzzled than ever.

What is confusing them is the timing of the tale. New observations made by a Caltech team with the Keck 10-meter telescope in Hawaii suggest that walls and voids may have already been common in the universe billions of years ago, when the conventional accounts of structure formation say the process was just getting started. The team, Judith Cohen, David Hogg, Michael Pahre, and Roger Blandford, reported in *Astrophysical Journal Letters* last month that 60% of the galaxies they charted in a deep, narrow sky survey fell within five wall-like structures spaced at irregular intervals over roughly 5 billion light-years. If that conclusion stands up—and new, unpublished data suggest it will—it "extends the formation of these structures way back in time," says Cohen.

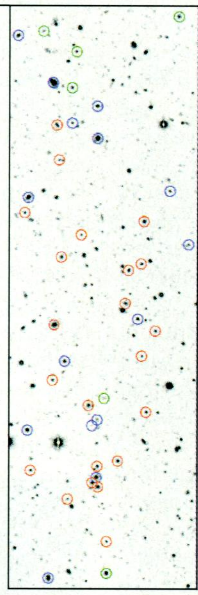
It may also conflict with the kind of universe favored by many theorists: one that contains enough mass to bring its expansion to a halt, given infinite time. In more tenuous universes, cosmic expansion quickly weakens the long-range gravitational interactions by which structures coalesce, so they have to form early. But a heavier cosmos can be more patient in pulling together the filaments and walls seen today. "If you've got large-scale structure early on," says Margaret Geller of the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts, "you've got a problem" with a heavy cosmos.

Sky surveys use "redshifts"—the increasing displacement of galaxies' light toward the red end of the spectrum as they get farther away—to add depth to the two-dimensional pattern of galaxies dotting the heavens. Ten years ago, Geller and her CfA colleague John Huchra used a redshift survey to discover the Great Wall, a sheetlike collection of galaxies stretching over hundreds of millions of light-years in the nearby universe. More recent surveys (*Science*, 7 June, p. 1436) have shown that somewhat smaller walls, filaments, and voids—vast regions nearly empty of galaxies—are common in our cosmic neighborhood.

Such nearby surveys say nothing about how the structures got there. Several years ago a team including David Koo at the University of California, Santa Cruz; Alexander Szalay at Johns Hopkins University; Thomas Broadhurst of the University of California, Berkeley; and Richard Ellis at the University of Cambridge began looking for clues by making "pencil beam" surveys that measured the redshifts of galaxies out to more than a billion light-years away. They found clumpy structure as far as they could see, far enough to make theorists uncomfortable.

The discomfort abated, however, with the larger and deeper Canada-France Redshift Survey (CFRS), a multi-institutional effort in five different parts of the sky, which surveyed 600 galaxies out to distances roughly three times farther than those in the survey by Koo and colleagues. Although CFRS found at least one coherent structure in deep space, says team member Simon Lilly at the University of Toronto, "the [distant] clustering was quite weak." That implied that the pronounced clumping seen today must have developed relatively quickly since then—in general accord with theorists' expectations.

The Caltech results, however, turn up the discomfort level again. The group relied on a so-called "multislit spectrograph" built by Cohen and Beverley Oke, which can make 30 of the time-consuming redshift measurements at once, to chart 106 galaxies out to slightly greater distances than those of the CFRS. Instead of choosing their galaxies from images made in visible light, they used infrared images. In the nearby universe, the cooler, older galaxies seen in such images tend to be more clustered, perhaps because gravity has had longer to draw them together, and the group wondered whether this tendency would persist at greater distances.


COHEN *ET AL.*

Long view. Colors indicate galaxies belonging to three distant structures.

It did. "By just looking at [the data] in a very cursory way, you can immediately see what we are calling large-scale structures," says Pahre: five peaks in the density of galaxies along the line of sight. The team argues that the peaks are likely to indicate structures the size and shape of the Great Wall, but dozens of times farther away.

Early clustering is also turning up in several other patches of the sky, where members of the Caltech team along with Lennox Cowie, Antoinette Songaila, and Esther Hu at the University of Hawaii are using the Keck to collect redshifts. The results have yet to be published, but the clustering is even emerging in one patch, mapped by the Hubble Space Telescope, that includes the faintest and most distant galaxies ever observed (*Science*, 26 January, p. 450). For Szalay, the conclusion is clear: "On very large scales, there is much more structure than anybody thought."

Whether the red galaxies that show this distant clustering really are the best tracers of the rest of the universe's matter, most of which is unseen, or "dark," is still an open question. But if they have revealed the basic cosmic architecture, it may be an emptier universe than theorists would like.

–James Glanz