times the normal rainfall in the Arizona-California desert, where precipitation ranges from 7 to 30 centimeters a year. The rule of thumb, Dimmitt says, is that fall rains and cool, wet winters—the classic El Niño pattern—favor lupines, daisies, and other winter-germinating annuals. But total moisture is "less than half the story," he adds. During some wet years, Dimmitt says, grasses—not flowers—come out in force, along with other plants that paint the desert green but neglect the rest of the palette. Even in this year's prime wildflower conditions, some desert pockets responded only modestly.

One reason for this pattern, says Dimmitt, is that the flowers engage in "temporal niche separation," in which species occupy the same tract by each thriving in years with different climates. In 1979, for instance, owl clover reigned. But this year the fuzzy purple flower "was almost nonexistent," he says, perhaps because early rains last fall favored other species. Dimmitt is compiling photos of past blooms to compare with weather data to better understand which wildflowers thrive under which conditions.

Another reason why a wet winter might not draw a full response from some flowers is "bet hedging," says University of Arizona, Tucson, ecologist D. Lawrence Venable. He compares the tactic to investors who avoid buying a single stock: They might make a heap of money, or they might go broke. The same can happen to a flower population that bets everything on a wet year—in this case, going broke means extinction. That's because sprouts that germinate after the first rainfall stand a risk of getting parched in a later drought.

Bet-hedging models predict that the drier the environment, the more important it is to a flower population's survival that only a small fraction of its seeds germinate in any given year. A just-completed study on Indian wheat seeds suggests that prediction may not hold in Arizona, says Venable grad student Maria Clauss. After receiving comparable levels of precipitation, seeds from scorching southwestern Arizona actually appeared to have higher germination fractions than seeds from regions near Tucson that usually get up to three times as much rain. Clauss thinks she knows why: In the harsher desert areas, many winters bring no measurable rain, and then El Niño rolls in with repeated drenchings. This means that if it rains at all, it's likely to rain a lot, and the best survival strategy may be for seeds to bet heavily on El Niño: Germinate early and in large numbers.

Still, just how temperature, rainfall timing and amount, and plants' own strategies interact to cue an El Niño bloom remains a mystery. "When it starts to rain, nobody can predict if it's going to be a good wildflower year," says Dimmitt. "I don't make predictions."

–Richard A. Lovett

Richard A. Lovett is a writer in Portland, Oregon.

COSMOLOGY

Cosmic Web Captures Lost Matter

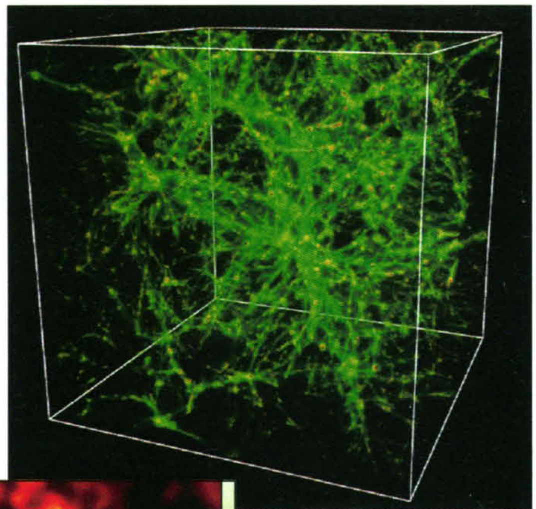
SAN DIEGO—Like the parents of acquisitive toddlers, astronomers have gotten used to losing sight of items they know must be around somewhere. At least 90% of the matter in the universe, for instance, must be in some exotic "dark" form that has not yet been seen directly. More irritating to some astronomers is that they cannot even see most of the universe's ordinary, or baryonic, matter. Billions of years ago—in the era visible in the most distant reaches of space—the missing baryons (protons and neutrons) formed sprawling complexes of hydrogen clouds. Then they vanished.

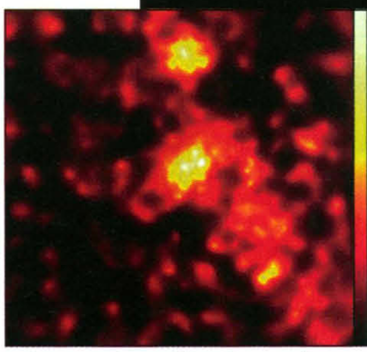
Or did they? In a talk at an American Astronomical Society meeting here earlier this month, Jeremiah P. Ostriker, a cosmologist who is also provost of Princeton University, predicted that observers will soon find most of the ordinary matter in the universe right under their noses—resting on the kitchen table, so to speak. Computer simulations by Ostriker and Princeton's Renyue Cen show that the primordial clouds condensed over time into a vast, filamentary network of fully ionized gas, or plasma—a cosmic cobweb that now links galaxies and galaxy clusters.

In the process, the simulations say, the plasma heated up to about a million degrees kelvin, so it now gives off a faint x-ray glow that is extremely difficult to detect with present satellites. If Cen and Ostriker are right, "most of the baryons could live in this warm intergalactic medium and be nearly invisible," says August Evrard, a cosmologist at the University of Michigan, Ann Arbor. Soon-to-be-launched satellites, like NASA's Advanced X-ray Astrophysics Facility (AXAF), ought to be able to see the plasma, said Ostriker: These missions "have a fair chance of finding most of the baryons in the universe." And at the end of Ostriker's talk, one x-ray observer announced that he may already have seen a hint of these hot filaments.

Cen and Ostriker's simulations take their lead from what has become the standard picture of structure formation in the universe. In this view, the dark matter's gravity slowly amplifies slight ripples in the primordial universe. As the waves steepen, the baryons collect like froth at the top of the waves, where the density is greatest.

That froth gave rise to filaments and clusters of galaxies and, when the universe was less than half its present age of roughly 13 billion years, to vast gas clouds. Neutral—non-ionized—hydrogen in the clouds absorbed the light of even more distant beacons called quasars, making the gas visible to observers today. The densely packed spikes of absorption in the quasars' spectra give these distant clouds their name—the Lyman-α forest—and let observers gauge how much baryonic matter they contained.





Gravity's gossamer. A simulation shows how primordial clouds might have collapsed into a plasma web over hundreds of millions of light-years; an x-ray observation *(left)* may show a hot spot in the network.

Astronomers can then compare the mass of the clouds with the total amount of baryonic matter that must have emerged from the big bang, which can be gauged from chemical tracers such as the amount of deuterium that survived the explosion (*Science*, 7 June 1996, p. 1429; 10 January 1997, p. 158). Although the comparison is fraught with uncertainties, the two numbers suggest that 80% to 90% of the baryons made in the big bang can be found in the ancient forest. "We have it tied pretty solid," says Michael Rauch of the California Institute of Technology in Pasadena.

In the billions of years since then, some of the gas has been consumed by star formation and sucked into the cores of great clusters of galaxies, where it is heated to hundreds of millions of degrees and gives off bright, easily detected x-rays. But all of those reservoirs account for less than half of the original baryons. "The question is, where has the other stuff gone?" says Rauch.

Cen and Ostriker's simulations suggest that most of it is still wafting out there in intergalactic space. As gravity continued its work, the simulations show, the clouds collapsed into a network of filaments. "The metaphor of waves breaking is right," said Ostriker: The collapse generated turbulence and shock waves, which heated the baryonic "froth" from less than 100,000 degrees kelvin to more than 1,000,000 degrees. That's hot enough to ionize all of the neutral hydrogen but not so hot that the plasma would outshine the obscuring gases in our own galaxy by very much.

Evrard is reserving judgment on some of the conclusions until he sees the details of the physics code, which Cen and Ostriker will report later in a paper they say is now under review at *Science*. But just after Ostriker finished his presentation, he got the kind of response every theorist dreams of. Q. Daniel Wang, an astronomer at Northwestern University, raised his hand and said that he may already have found a faint gleam from the filamentary plasma in measurements from the Roentgen x-ray satellite (ROSAT). In one observation, Wang may have seen the warmest part of the network directly (see graphic). In another, he attempted to subtract out the foreground glare of our galaxy, revealing what could be the general background glow of the network.

Wang says he has already been awarded observing time on AXAF—scheduled for launch later this year—which has better sensitivity and spatial resolution than ROSAT can muster. More evidence for the misplaced baryonic matter, if it's there, could come quickly.

–James Glanz

MICROBIOLOGY

Possible New Weapon for Insect Control

In the past 15 years, genetic engineers have created new strains of crop plants with their own built-in insecticides: bacterial toxins that can kill insect pests that munch on the plants. It's an elegant scheme, promising to keep harmful insects in check without exposing other organisms to insecticidal sprays. But so far the plant genetic engineers have had to rely on only a few types of toxins, from the bacterium *Bacillus thuringiensis* (Bt). This has raised concerns that the target insects will become resistant to the Bt toxins, leaving the plants defenseless. Now, scientists have identified a promising new group of toxins that might eventually be used instead of Bt, or in combination with it.

On page 2129, a team led by Richard ffrench-Constant, an insect toxicologist at the University of Wisconsin, Madison, reports the discovery of proteins that the bacterium *Photorhabdus luminescens* uses to kill a wide variety of insects, including common pests. "This provides evidence for a category of insecticides that we didn't know about before," says David Fischhoff, president of Cereon Genomics, a Monsanto subsidiary, in Cambridge, Massachusetts.

The researchers also showed that the toxins work when eaten by an insect pest—a prerequisite for use in genetically altered plants. They now hope that toxin genes from *P. luminescens* can eventually be used, like the Bt toxin genes, to produce new strains of insect-resistant plants. Combining the new toxins with Bt could ease the resistance problem, they say, in part because an insect is very unlikely to become resistant simultaneously to two toxins, as long as they kill by different mechanisms.

This quest for new insecticide genes has led researchers to some odd places, including the gut of certain roundworms, the heterorhabditid nematodes, where *P. luminescens* resides. Some gardeners use this nematode as a natural form of insect control. It wriggles into the circulatory system of an insect and releases the bacteria, which produce something that "turns the insect into soup," as ffrench-Constant puts it. The nematode reproduces in the carcass, producing tens of thousands of young, each of which swallows a dose of bacteria before emerging and seeking new victims. "It makes *Aliens* look like a picnic," says ffrench-Constant.

Although scientists have known about this phenomenon for some time, no one had chased down the *P. luminescens* toxin. David Bowen, Michael Blackburn, and Thomas Rocheleau in ffrench-Constant's lab have now done so by growing *P. luminescens* in lab cultures and tracking the toxic activity to proteins purified from the broth in which the bacteria were grown. They found it in a high–molecular-weight protein fraction, composed of four complexes, designated A through D, each of which weighs about a million daltons.

Glowworms. The bacterium *P. luminescens* lights up in and kills tobacco hornworms.

PHOTO: R. BHARTIA, C. DIZACK

Because *P. luminescens* normally enters the insect circulatory system, ffrench-Constant and his colleagues didn't know whether the toxins could kill when taken by mouth. But when they fed complex A to tomato hornworms, the insects died. The team has since found that complex D also has high oral toxicity, while B and C have little effect on the tomato hornworm. The researchers don't yet know exactly how the toxins work.

To find the toxin genes, the Wisconsin team raised antibodies to the complexes and used them to probe a library of *P. luminescens* genes expressed in cells of the bacterium *Escherichia coli*. Once the researchers identified the genes, they went on to prove that the isolated proteins, and not a minor component in their test mixtures, were indeed the toxins. They did this by engineering *P. luminescens* bacteria that couldn't produce the proteins.

As predicted, bacteria missing either complex A or D were less toxic to insects than the wild-type strain, while a strain lacking both complexes was harmless. "The nematodes have been used for some time in insect control as an organic gardening tool, but it's only now that we're beginning to understand the molecular basis for how the bacteria kill the insect," says ffrench-Constant. "In doing that, we've discovered a potential biopesticide."

Many challenges remain before the newly discovered molecules might be used in crops, however. When the researchers introduced the toxin genes into *E. coli*, for example, the bacterial cells made the proteins but did not secrete them, and they were not toxic. This result suggests it might be difficult to coax plants to produce the proteins in active form. The researchers are currently trying to identify other molecules that *P. luminescens* requires to export the toxins from the cell and activate them. In addition, tests are just getting under way to see if the toxins are safe for humans and wildlife, as the Bt toxins are. Still, scientists are encouraged.

"It's always good to find a novel way to control insects," says Bruce Tabashnik, an entomologist at the University of Arizona, Tucson. And, he adds, because many insect-killing nematodes harbor bacteria, there may be other, related insecticidal toxins. "It's a whole new realm, waiting to be explored," Tabashnik says.

–Evelyn Strauss

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