Cosmos in a Computer

Simulations suggest monster clusters may lurk in the distant universe

By RON COWEN

Folks, you ain't seen nothin' yet.

Theorists who spend their time modeling what the universe looked like long ago say that there may be some big surprises in store. As a new fleet of telescopes starts scanning distant reaches of the heavens, it may reveal huge clusters of galaxies that gravity pulled together when the universe was still in its first blush of youth.

Extremely rare, these "monster clusters" would have been twice as massive as the typical cluster found in the universe today, and much hotter, says August E. Evrard, a cosmologist at the University of Michigan in Ann Arbor. He and an international team of astronomers, known as the Virgo Consortium, have created a comprehensive computer simulation of the entire cosmos and have found that it predicts the enormous, distant groups of galaxies.

"The standard lore would say that [any large] clusters formed relatively recently," Evrard says. It takes time for gravity to assemble larger objects from smaller ones. Because distant objects are observed at a stage early in the universe's history, "you would naively expect that the hottest, most massive clusters would be nearby, somewhere in our cosmic backyard."

However, says Evrard, the Virgo computer model shows the largest, hottest cluster already in place when the universe was just 5 billion years old, about one-third its current age. Moreover, the cluster has a temperature "higher than any known cluster in the sky today." Evrard will present his team's findings next week at a meeting of the American Astronomical Society in Chicago.

During the next few years, the team's model will be put to the ultimate test. If gargantuan assemblages of galaxies from distant reaches of the universe do exist, spacecraft mounted with precision X-ray and microwave telescopes should capture images of these clusters.

Because the monsters turn up only in models that assume that the expansion of the universe is speeding up rather than slowing down, their appearance in telescope images would provide a strong piece of evidence for that portrayal of the cosmos.

So far, the Virgo scientists have revealed one hot, massive cluster in their analysis of one-fourth of the sky. The team plans to extend its model soon to cover the sky's full breadth.

It's a big job to model the entire cosmos. Four programmers spent a year preparing the software to run on an SGI/Cray T3E parallel supercomputer, replete with several refrigerator-size racks of workstations, at the Garching Computing Center of the Max Planck Society in Germany (SN: 7/4/98, p. 11). It took Evrard and the Virgo team, led by Carlos S. Frenk of the University of Durham in England and Simon D.M. White of the Max Planck Institute of Astrophysics in Garching, another year to generate and analyze more than a terabyte of data from the large simulations.

Representing the mass density of the universe with 1 billion virtual particles, the simulations show how gravity gradually sculpts the particles into a spidery network of filaments. As time goes on, the network grows more complex and the structures within it grow larger.

Myriad other simulations—as well as blackboard calculations that use analytic equations rather than computers to approximate the growth of the cosmos—previously revealed a spidery structure and hinted at early clustering. However, these models either examined smaller swaths of the universe or used fewer particles to simulate the evolution of matter. Such models can't as clearly reveal the development of large but extremely rare structures.

"Because the [massive] clusters are so rare, one requires a large simulation," to discern them, says Michael L. Norman of the University of Illinois at Urbana-Champaign.

"One of the things that this large simulation allows us to do is to look at the details of rare events,"

Swath of the universe, as seen in the Virgo Consortium's most recent computer model. The present time appears at lower left, and the distant past, 14 billion years ago, at upper right. This model assumes that the expansion of the universe is accelerating. Red denotes highest density of matter, blue-green the average, and blue-black the lowest. Arrow indicates the approximate position of the monster cluster.

All images provided by Evrard/Virgo Consortium

says Evrard. "If you see one or two [monster clusters] in this volume, you start to feel confident that there really are a few in our observable universe."

Evrard notes that the simulations track only the cold dark matter—the unseen, slowly moving material that responds to gravity but not electromagnetic or other forces. Thought to make up as much as 99 percent of the mass of the universe, cold dark matter easily gathers into clumps. Astronomers generally believe that galaxies nestle within the densest concentrations of this mystery material. By assuming a particular relationship between the distribution of dark matter and the visible gas and stars that comprise galaxies, the researchers can indirectly investigate how galaxies mature and cluster.

Unlike most other computer simulations of the universe, the Virgo model takes into account the finite speed of light when generating pictures of the sky. This feature enables astronomers to directly compare predictions by the computer model with actual telescope surveys of the universe.

Astronomers studying a galaxy 1 million light-years away view the starlit body not as it appears now, but as it looked 1 million years ago when the light now reaching Earth left the galaxy. Indeed, the deeper a telescope looks into space, the farther it peers back in time, providing a snapshot of what the cosmos looked like long ago.

"The computer simulations can be rearranged so that you look at the past history [of the universe] just as if you were using a telescope," comments Richard S. Ellis of the University of Cambridge in England. "You construct a mock catalog of galaxies that allows you to see what an observer would see if he looked out in the sky."

Results of the simulations can be matched to telescope scans already under way, Ellis says. These include the mammoth Sloan Digital Sky Survey, designed to map the location of more than 1 million galaxies over one-quarter of the sky (SN: 1/23/99, p. 57), and the 2dF Galaxy Redshift Survey, which will determine the location of 250,000 galaxies over a narrower field of view.

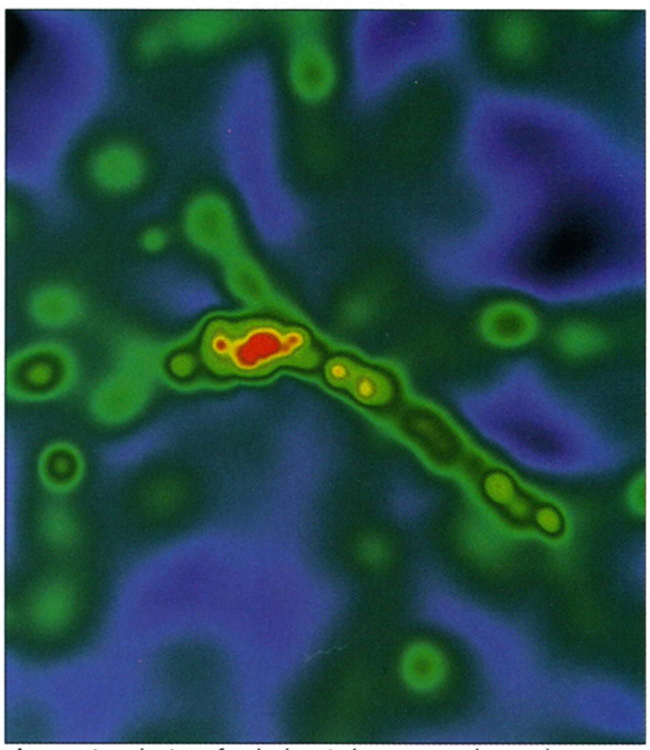
Several new telescopes have an even better chance of detecting monster clusters. These groupings of galaxies are expected to radiate abundant X rays, and two satellites scheduled for launch within the next several months may detect the emissions, notes Norman.

The Chandra X-ray Observatory, which will discern faint X ray–emitting objects in greater detail than any previous telescope, is now scheduled for launch in July. The X-ray Multi-mirror Mission, set for launch next January, features three X-ray telescopes that will record with high precision the intensity of emissions over a wide range of X-ray energies. Together, says X-ray astronomer Richard Mushotzky of NASA's Goddard Space Flight Center in Greenbelt, Md., the two satellites may be able to gauge the mass and temperature of clusters as distant as the one in the computer model.

"The X-ray sky is going to be a lot more interesting place than people had ever imagined," asserts Evrard.

Mushotzky notes that observers already have some evidence for galaxy clusters that may fit the model. X-ray images taken by the German-British-U.S. satellite ROSAT and spectra taken by the Japanese satellite ASCA indicate the existence of a few relatively distant galaxy clusters, but the data aren't good enough to determine whether the clusters are as massive and as hot as the ones that Evrard's team predicts.

Two other satellites, which will scan the sky for much lower-energy radiation, may also ferret out distant, massive clusters. NASA's Microwave Anisotropy Probe (MAP) is scheduled for liftoff next year, and the European Space Agency's Planck is expected to be launched in 2007. With greater detail than ever before, they will examine the cosmic microwave background, which is the faint echo of radiation left over from the Big Bang, and record tiny ripples—hot and cold spots—in the otherwise uniform glow from this background.



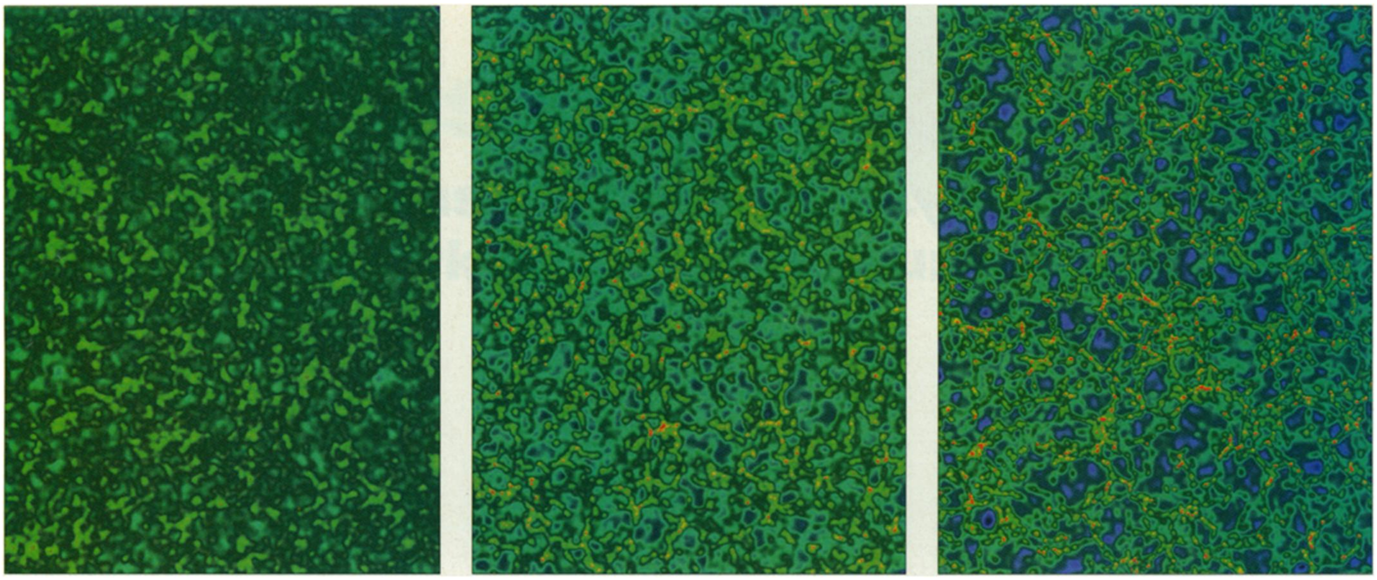
A monster cluster of galaxies, twice as massive and considerably hotter than the typical cluster in the universe today, was already in place when the cosmos was just one-third of its current age, according to the new simulation. Red indicates highest density.

Roughly speaking, the hot and cold spots correspond to regions in the universe that, a mere 300,000 years after the Big Bang, had slight underdensities or overdensities of matter. These minuscule fluctuations in the distribution of matter are considered the seeds from which all of the structure in the universe arose.

When photons—particles of light—from the microwave background pass through a hot, massive cluster, they collide with electrons in the gas that resides there. The electrons impart some of their energy to the photons, kicking them up to higher microwave energies. A radio telescope would thus observe a shortage of lower-energy, lower-frequency microwave photons. This deficit is a tip-off that a massive cluster of galaxies resides there (SN: 10/22/94, p. 265).

Because the massive clusters are predicted to be so scarce, telescopes "may have to search a large fraction of the sky before [they] hit pay dirt," Evrard notes. For this reason, the Planck mission, which will record tinier fluctuations in the microwave background than MAP does, is more likely to find evidence of early clusters.

On the ground, new arrays of radio telescopes will join the search. John E. Carlstrom of the University of Chicago and his colleagues describe a proposal for such an array in an article posted on the Internet (http://xxx.lanl.gov/abs/astro-ph/9905256).



Blow-up of a section of the model (left) depicting the distant, early universe shows that when the cosmos was just 1.4 billion years old, galaxies had yet to concentrate into massive assemblages. (Center) Large clusters of galaxies began forming when the universe was about 4.6 billion years old. The red islands are regions where clusters are beginning to congeal. (Right) The nearby universe, according to the model, has huge voids surrounded by large complexes of superclusters.

The simulations incorporate evidence from recent observations that suggest some unusual kind of energy is driving the universe to expand faster and faster, like an inflating balloon whose girth grows at an accelerating rate (SN: 12/19&26/98, p. 392). This energy, represented in Albert Einstein's equations of general relativity by the so-called cosmological constant, opposes the familiar inward tug of gravity.

"We're making a prediction that if we do live in [a universe with a cosmological constant], then you shouldn't be surprised to find a lot more very hot clusters out there," Evrard says. "In fact, the hottest, most massive clusters have yet to be discovered." When the theorists performed simulations without a cosmological constant, they saw no sign of monster clusters at early times in the universe.

Observing such clusters would support the theory of an accelerating universe, says Norman.

"The presence or absence of distant, massive clusters is one of the best discriminants between different models of the universe," agrees Martin J. Rees of the University of Cambridge's Institute of Astronomy.

Over the next few years, astronomers stand poised to find out whether these monsters prove to be more than paper tigers. "The observational quest will be exciting," says Norman. □