constant of 64 kilometers per second per megaparsec (1 megaparsec equals 3.26 million light-years), a figure many astronomers find plausible.

Cosmic slowdown. Now, by finding, correcting, and analyzing supernovae at much greater distances (as much as 7 billion light-years), the Perlmutter and Schmidt groups are learning how this expansion rate has changed over cosmic history. In the nearby universe, where the expansion hasn't changed much, the corrected brightnesses of the supernovae should fall along a straight line when plotted against redshift. For supernovae in the far-distant, long-vanished universe, however, the line should begin to bend, indicating that the expansion rate was different at earlier times.

The amount of bending holds clues to the "geometry" of the cosmos—whether we live in an "open" universe, doomed to expand forever, a "closed" universe that will eventually recollapse, or the state just in between, which theoretical cosmologists prefer because it is predicted by a favorite scenario for the early universe called inflation. Two factors can change the expansion rate, thus bending the line: the mass density of the cosmos—expressed as omega, the ratio of the actual density to the density predicted by inflation—and the cosmological constant.

Most theorists would prefer the cosmological constant to be zero, because they have no good way to justify any other value. But there is strong motivation to accept a positive value: This property of empty space could increase omega, reconciling the density predicted by inflation with the apparent lack of mass in the universe. All the visible stars and galaxies provide an omega less than 0.01, and even tallying all the invisible "dark matter" suggested by indirect measurements brings omega up to only 0.2 or 0.3. A cosmological constant could push omega up to the long-sought 1.0.

Fortunately, mass and a cosmological constant have different effects on the way the expansion rate varies over time. With enough distant supernovae at a range of different redshifts, astronomers should be able to disentangle these effects. The Perlmutter and Schmidt groups have used automated techniques to spot scores of distant supernovae, but analyzing and correcting these observations require months of effort. They also require waiting a year or so to make follow-up observations of the supernova host galaxies, so that the galaxies' own light can be subtracted from the supernova measurements.

With only seven distant supernovae analyzed so far, covering just a modest range in redshift, the Perlmutter group can only hint at the answer. But their preliminary results suggest that mass accounts for an omega of about 0.9, implying the existence of vastly more dark matter than has been traced so far, and the cosmological constant for an effective omega of only 0.1. The uncertainties are broad, however, leaving open the possibility that matter accounts for an omega as small as 0.3 and that the cosmological constant has a substantial value.

The Perlmutter group's competitors say even this level of accuracy may be overly optimistic. "The actual [uncertainties] may be larger than those that are quoted," says Kirshner, who notes that those in the Perlmutter group followed different procedures in observing their distant supernovae from the ones that Hamuy, Phillips, and Suntzeff used when they learned how to correct nearby supernovae to a standard brightness. What's more, says Schmidt, the Perlmutter group observed their first seven supernovae in one color, even though two or more colors give a better indication of reddening and dimming from dust.

Richard Ellis of Cambridge University in the U.K., a member of Perlmutter's group, responds that "even with the best will in the world, it is not possible to treat low- and high-redshift data identically" because of differences in the intensity and colors of light from near and distant supernovae. Ellis adds that the Perlmutter group has done a better job at finding the farthest of these beacons, having cataloged some that lie twice as far away as their first seven.

More detailed analysis of these and the dozens of other distant supernovae that the Perlmutter and Schmidt groups have observed will narrow the uncertainties. Both groups have been assigned large amounts of time on the Hubble Space Telescope during its next observing cycle, which begins this July, for follow-up observations of the supernova host galaxies. And by the end of 1998, both should have completed their work and had a chance to compare it. "I won't believe 'the answer' unless we both get the same answer," says Riess. Perlmutter concurs: "It's great that there are two projects—there are so many things you can do wrong. Of course, we started first, and we would like to have our results out first."

Either, way, thanks to Type Ia supernovae, cosmologists now stand on the threshold of knowing the shape of the universe—and the shape of things to come.

–Donald Goldsmith

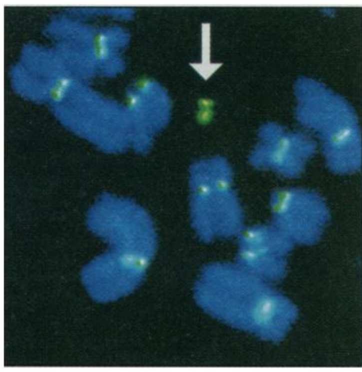
Donald Goldsmith's most recent book on astronomy, Worlds Unnumbered: The Search for Extrasolar Planets, *has just been published by University Science Books of Sausalito, California.*

MOLECULAR BIOLOGY

Counterfeit Chromosomes for Humans

The name is not very elegant—YACs, standing for yeast artificial chromosomes. But for about a dozen years, these artificial constructs, containing the minimal elements of a functional chromosome, have been the basis of some elegant science. They have both aided understanding of yeast chromosome function and served as vehicles for cloning large genes from any species, using yeast cells' own DNA-replication machinery. Now, however, YACs may have to share the spotlight with HACs: human artificial chromosomes.

In this month's issue of *Nature Genetics*, researchers at Case Western Reserve University and Athersys Inc., both in Cleveland, report constructing the first wholly synthetic, self-replicating, human "microchromosomes," one-fifth to one-tenth the size of normal human chromosomes. While the team still hasn't found an efficient way of transplanting microchromosomes' self-assembling components into new cells—a crucial step before researchers can exploit them fully—future refinements could give HACs even broader research applications than YACs.



ATHERSYS INC.

HAC for hire. Humanmade microchromosomes (arrow) could shelter supplementary human genes.

"They have created a system where they can now do a great deal to analyze [human chromosome] function," says David Schlessinger, a genome researcher at Washington University in St. Louis. Custom-made HACs could, for example, help reveal how each gene's chromosomal packaging affects its activity. And there may also be medical payoffs: These chromosomes-in-miniature could be loaded with genes that are missing or impaired in patients with genetic disorders such as muscular dystrophy, then introduced into the patients' cells to compensate for the defect.

Biologists have wanted to mimic human chromosomes ever since they performed the feat for yeast. To make YACs, researchers combine telomeres, the protective DNA segments on the ends of chromosomes; centromeres, which serve as attachment points for the protein fibers that pull duplicate sister chromosomes (chromatids) apart during cell division; and origins of replication, DNA segments where the double helix can unwind and begin to copy itself. "YACs showed us that this type of thing could be done in yeast, but there was no guarantee that it could be done in human cells, because human chromosomes are much more complex," says molecular biologist Gil Van Bokkelen, president of Athersys and a co-author of the *Nature Genetics* paper with Case Western researchers John Harrington, Robert Mays, Karen Gustashaw, and senior author Huntington Willard.

The members of the Ohio team believe that they succeeded because they decided to add non–protein-coding "satellite DNA," repeated sequences of five to 171 base pairs found near mammalian centromeres, to their HAC recipe. Some researchers regard the satellite sequences as nonfunctional "junk DNA," but from earlier studies, Willard's team had concluded that the alpha type of satellite is actually the centromere's main component.

In the current work, the researchers first devised a way to build long strings of alpha satellite DNA. They then inserted the satellite arrays into cultured human tumor cells, together with DNA fragments from telomeres and plain "genomic" DNA, including origins of replication. Some of the satellite arrays combined with DNA fragments, forming microchromosomes 6 million to 10 million base pairs long. These apparently replicated when the tumor cells divided, because 6 months later, the progeny cells still contained HACS.

To use HACs to uncover more about how real chromosomes work, experimenters will need a more reliable method than the current vehicles—lipid bubbles called "lipofectins"—to get HACs or their ingredients into cells. But with refinements, Willard says, HACs could help settle just what centromeres are made of and a host of other questions in molecular biology and biomedical research.

In addition, any gene sandwiched between the synthesized satellite arrays and telomeres would, in theory, behave like a gene on a regular chromosome, because it would be accessible to enzymes, transcription factors, and the other machinery of gene expression and replication. Thus, HACs could give biologists a new way to study gene activity in human cells and gene-therapy researchers a new way to transfer needed genes into patients' cells. "YACs really aren't good for that—they are not stable in human cells," says Louis Kunkel, a leading muscular dystrophy researcher at Children's Hospital in Boston. "This is a neat alternative."

–Wade Roush

PHYSICS

New Proof Hides Cosmic Embarrassment

Stephen Hawking is betting his shirt again. Earlier this year, the Cambridge University astrophysicist conceded one wager about the hypothetical ruptures in the laws of nature called singularities. This time, Hawking has a better chance of winning, according to a new theorem by Princeton University's Demetrios Christodoulou to be published in the *Annals of Mathematics*.

The original bet, made in 1991 between Hawking and two physicists at the California Institute of Technology—Kip Thorne and John Preskill—concerned whether "naked" singularities could ever form in the universe. Singularities, points of infinite density formed when matter or field energy collapses, are hypothesized to exist within black holes, which "clothe" them, but Preskill and Thorne argued that under just the right circumstances, they might also form on their own. Hawking insisted that they cannot.

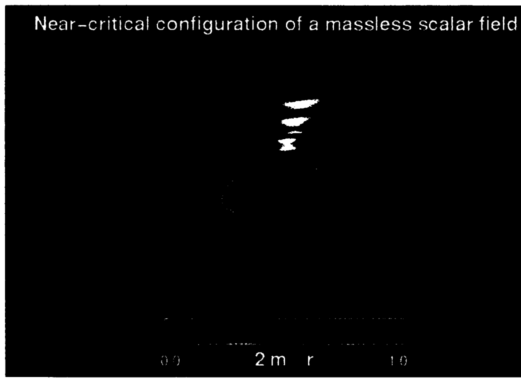
This may sound like a recondite dispute among specialists, but it strikes at the heart of what cosmologists think they know about the fabric of space and time. "I would consider it the most significant question that can be posed entirely within the confines of classical, general relativity," says Robert Wald, a cosmologist at the University of Chicago. Because Einstein's mathematical description of space-time breaks down at singularities, they would in effect throw the universe into unpredictability if they could be observed and their effects felt. "It's ignorance where ignorance really matters," says Christodoulou.

In the 1970s, Oxford University's Roger Penrose had offered some reassurance with his "cosmic censorship" conjecture, which said that singularities could never be directly observed because they would always be shrouded in black holes, from which even light can't escape. Hawking has drawn on the conjecture in some of his best known work, but Preskill says that "it would not be that surprising or terrifying to me if [cosmic censorship] weren't true." Thorne agreed, leading to the 1991 bet.

"Unfortunately, I wasn't careful enough about the wording of the bet," Hawking said during a symposium on black holes in Chicago last December (*Science*, 24 January, p. 476). The wording didn't exclude naked singularities born in circumstances likely to be extremely rare in nature—for example, conditions precisely poised between black-hole formation and a less drastic collapse. Such naked singularities are allowed theoretically, according to earlier work by Christodoulou and computer calculations by Matthew Choptuik of the Center for Relativity at the University of Texas, Austin.

"Kip and I started pressing Stephen that, well, he should pay up," says Preskill. A story in the 12 February *New York Times* reported that Hawking had finally decided to settle the wager, which required the loser to hand over clothing embroidered "with a suitable concessionary message." Hawking's chosen message, printed on a T-shirt: "Nature abhors a naked singularity."

"We said, 'This is a concession? It sounds like fighting words,'" recalls Preskill. But Christodoulou's new theorem lends support for Hawking's not-so-concessionary posture, by proving mathematically—without the approximations of the earlier computer calculations—that infinitesimal changes to the special, naked singularity–forming collapses will produce black holes instead. The proof assumes that the matter or energy collapses spherically, so it doesn't rule out the possibility of naked singularities born in more complicated geometries. But for spherical collapses, it shows that Christodoulou and Choptuik's earlier solutions "were very much of the character of a pencil standing on end," says Wald. "In nature, you're never going to find pencils standing on their ends." In light of his new theorem, says Christodoulou, "I don't think [Hawking] should have paid up."



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Censored. Collapsing shells of field energy (ripples) form a singularity cloaked within a black hole.

Now, the original participants have laid a new wager. The bet is the same, except that it is now limited to naked singularities that might develop from "generic"—meaning not unstable or impossibly rare—initial conditions. And this time, says Preskill, the clothing must be embroidered with a "truly" concessionary message. Although Christodoulou's proof says nothing about nonspherical collapses, Hawking says he isn't worried: "The world is safe from naked singularities, at least in classical general relativity."

–James Glanz