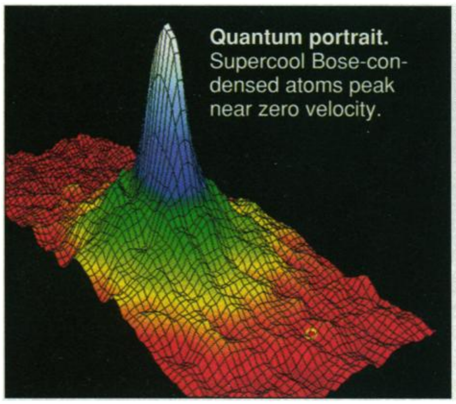
A New Form of Matter Unveiled

Physicists create the long-sought Bose-Einstein condensate, allowing easier exploration of quantum mechanics, while other researchers celebrate a new planet, a gene for eyes, brain images, and more

Back in 1924, Albert Einstein predicted the existence of a new phase of matter, an exotic state in which atoms defied the laws of classical physics and followed only the dictums of quantum mechanics. In 1995, by chilling wisps of gas to ultracold temperatures, physicists finally got their first good look at this state, named the Bose-Einstein condensate after Einstein and Indian physicist Satyendra Bose. This year's work ends an arduous quest and ushers in a new age of exploration in atomic and condensed-matter physics.

We salute the condensate as Molecule of the Year for 1995, but this peculiar form of matter is not a molecule. Indeed, this year's magnificent achievement was to elude the everyday forces that bind atoms together into molecules and so unmask the more subtle powers of quantum mechanics. While atoms in an ordinary gas dart about in all directions, the atoms in the condensate move in lock step, at identical speed and direction. They have relinquished their individual identities to become a single, collective entity, and their organized condition is expected to give rise to bizarre properties.

The condensate's unusual nature makes it an ideal workshop for exploring the counterintuitive realm of quantum mechanics. So 6 months after the first dramatic report, experimentalists are rushing to create and explore this new phase, while theorists calculate its properties. Physicists are already angling to apply the new knowledge, hoping to capitalize on the condensate's unique aspects to create a laser that shoots beams of atoms instead of light. Understanding the laws that govern matter in this cold, coherent state may help physicists understand the mysteries of superconductivity and perhaps even the early universe.



Quantum portrait. Supercool Bose-condensed atoms peak near zero velocity.

M. R. MATTHEWS

Physicists have glimpsed Bose-Einstein condensation before, but never in a system where they could study all its properties. For example, pairs of electrons and electron holes, known as excitons, have been observed to form condensates in semiconductors, but these last only a few millionths of a second. In ultracold liquid helium, up to 10% of the atoms are thought to be Bose-condensed, and this is intimately linked to startling properties such as superfluidity, which allows this fluid to creep up the sides of a beaker. But in liquid helium, the condensate is modified by the classical forces between atoms, so the quantum-mechanical signature is muddied.

To create a pure condensate, physicists need supercold atoms, where no heat veils the quantum forces. Yet the atoms must be kept in a gaseous phase and prevented from collapsing into a solid or liquid. In July, by cooling atoms of rubidium to within a whisper of absolute zero, researchers at a lab run jointly by the National Institute of Standards and Technology and the University of Colorado managed this feat. In an ultracold cloud of gas, they saw their boldest dreams come true, as a textbook example of Bose-Einstein condensation took shape. When they graphed the distribution of the atoms' velocities, they saw a now-classic portrait, with a dramatic peak close to zero

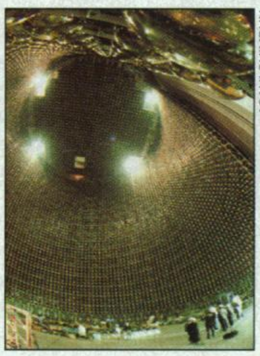
Gazing Into the Future: *Science*'s Crystal Ball

There's no scientific way to foretell the future, but here are our picks for hot research areas in 1996.

Test anxiety. The stream of newly identified genes has swelled to a torrent, making it possible to test adults, children, and even embryos for predisposition to a slew of genetic diseases. Options such as testing embryos for cancer genes are likely to inflame ethical debates in Europe and the United States.

Neutrino news. In 1995 neutrinos earned their discoverer a share of the Nobel Prize, but in coming years they could create even more of a stir. If these wispy particles have mass—as physicists worldwide hope to discover in the next year or so—they may help solve puzzles ranging from cosmic "dark matter" to the workings of the sun.

Bacterial warfare. An array of unrelated virulent bacteria possess a newly discovered weapon: the ability to deliver proteins and other molecules into target cells, perhaps to disarm them or disrupt their internal communications. Watch for new data on the molecular components of what's called a type 3 secretion system, and how this helps bacteria vanquish their hosts.



ASAHI SHIMBUN

Neutrino net. Detector aims to weigh neutrinos.

Xenophilia. Thanks to novel anti-rejection therapies, animal-to-human organ transplants may now be feasible; clinical test cases may come up soon in the United States and England. Count on media attention—and a healthy dose of scientific criticism from skeptics who feel the procedure is too experimental or too dangerous.

ALFRED THOMAS/ANIMALS ANIMALS

Organ donor? Xenotransplants move forward.

Mental markers. Efforts to find genetic markers for mental illness have been fraught with false starts. But recently four independent teams of geneticists concluded that an area on chromosome 6 is linked to schizophrenia in some families. Next step: using these results to find the gene itself.

Life in the '90s. What organisms thrive in oil wells, solid rock, and the searing heat of deep sea vents? Extremophiles do, and these microbes with a yen for the wild side are hot properties in biology and chemistry, thanks in part to their potential industrial uses. In 1995, researchers identified the crystal structures of enzymes from these one-celled wonders. Expect more in '96, as scientists sequence the microbes' genomes and continue to probe how their proteins survive extreme conditions.

G whiz. Two small G proteins named Rac and Rho have recently been revealed as central switches in the cellular communication network. The pair sends signals that not only help trigger cell movement—their traditional role—but also prompt cell proliferation and gene transcription. Expect biologists to rapidly uncover details of these signaling pathways and learn more about their physiological roles.

ILLUSTRATIONS BY TERRY E. SMITH

The Bell Tolls at AT&T

Corporate America has been quietly phasing out basic research for years, but since 1925 industry has had at least one leader in fundamental research: AT&T Bell Labs, birthplace of the transistor, stereo sound, and the UNIX operating system. But in 1995, the winds of change caught up with the labs at last.

This fall, officials announced that Bell Labs' parent, AT&T, will fragment into three companies; the labs will split in two. Company officials say the breakup won't trigger research layoffs. But analysts warn that the split will accelerate recent trends at the research giant, favoring applied over basic research and information sciences over the physical sciences. At Bell Labs, the new year may ring out the end of an era.

velocity that represents the atoms slowly emerging from the condensate.

This stunning achievement rests on a long history of research in condensed-matter and atomic physics, for the successful experiment marries several cooling techniques developed over the past 2 decades. The Colorado physicists slowed atoms with laser beams and trapped them in magnetic fields. They cooled their sample further with a method called evaporative cooling, which works much the way a cup of tea cools, by allowing the hottest atoms to escape. Surprisingly, these techniques are within reach of many physics labs around the world. The hardware itself is estimated to cost $50,000 to $100,000—a bargain price for observing a new form of matter.

The ability to create the condensate will allow researchers to study quantum behavior—typically seen only at the atomic scale or smaller—in a macroscopic system. For although the first condensate was only about the size of a living cell, physicists are making larger samples all the time. In the fall, researchers at the Massachusetts Institute of Technology created a condensate with 200 times as many atoms as in the first sample, by modifying the magnetic trap with lasers and using sodium atoms. And they did it in only 9 seconds as compared to 5 minutes, taking a giant step forward toward the goal of manufacturing quantities of condensate quickly. With this new phase of matter in hand, physicists have dozens of questions to explore, from whether the condensate is truly a superfluid to whether it absorbs, reflects, or refracts light.

In principle, nearly three quarters of the elements in the periodic table could enter Bose condensation, so this year's research opens the floodgates for studies on a variety of different elements and conditions. Indeed, in August, shortly after the Colorado experiment, a group at Rice University found evidence of Bose condensation using lithium atoms. Theirs is a provocative result, for theorists had predicted that these atoms would collapse into a lithium snowflake rather than staying as a gas long enough to enter Bose condensation.

Meanwhile, theorists are already busy making new calculations based on the 1995 experiments. Because Bose-Einstein condensation is related to superconductivity, this work may help solve the mystery of how certain materials manage to conduct current without resistance. Also, some astrophysical theories invoke an asymmetrical pattern of Bose condensation to explain the bumpy distribution of matter in the early universe, a distribution that eventually led to the formation of galaxies. Having an actual Bose condensate could help develop such speculations.

In the long run, this new form of matter may yield substantial benefit to industry and society as well. That's because the condensate is to normal atoms as a laser is to a light bulb. In laser light, all the photons are in precisely the same phase, a property that makes laser beams bright, powerful, and tightly focused. Similarly, the matter waves of atoms in a Bose-Einstein condensate are all in phase, and physicists are already working to design an "atom laser." Such a coherent beam of atoms could eventually pave the way for a new generation of incredibly fine manipulations and measurements. An atom laser might move atoms around one by one, or "write" atoms into semiconductors, much as lasers etch silicon chips today, but with much finer resolution.

All this is still far in the future. For now, physicists can delight in the fulfillment of a long-standing prediction and enjoy the heady feeling of exploring a newly accessible phase of matter.

–Elizabeth Culotta

And the runners-up are ...

In 1995, many fields of science made dramatic progress. We celebrate nine advances that expand scientists' knowledge and also offer great potential benefits to society.

Eyes everywhere. Developmental biologists have long sought to confirm the existence of "master control genes," individual genes that can single-handedly turn on the entire genetic program required to make a particular organ or tissue. But their quarry proved elusive until earlier this year, when researchers in Basel, Switzerland, showed that a gene called *eyeless* has the sweeping powers of a bona fide master control gene.

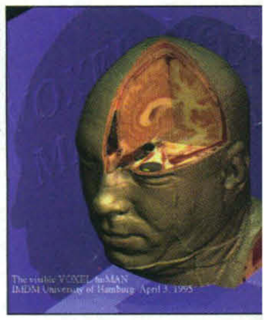

U. KLOTER AND G. HOLDER/BLOTZENTRUM

Eye-popping results. A single gene makes extra eyes *(in red)* form on flies' head and knees.

Biologists already knew that *eyeless* was necessary for eye formation in fruit flies. But in a spectacular experiment, the Basel team found that simply switching on *eyeless* in various parts of a fruit fly embryo could activate the entire cascade of genes needed to make an eye. Turning on *eyeless* caused fully formed eyes to pop up on a fly's wings, its knees, even on the tips of its antennae. One fly had 14 eyes in all. Researchers are now checking to see if any of these out-of-place eyes are hooked up to the nervous system, and if so, are they able to see.

This master switch also offers an important clue to the mystery of eye evolution. *Eyeless* is similar in sequence to human and mouse genes necessary for normal eye development, and the Basel researchers found that the mouse gene triggers eye formation in flies. After half a billion years of evolution, the eyes of mammals and flies still rely on the same master control gene.

Navigating the Net. In 1995, scientists of every stripe explored new information technologies that are transforming the business of research and teaching, from gathering raw data to teaching courses. Not only did the World Wide Web take science and society by storm, but a burgeoning set of new tools helped scientists navigate the flood of information.


UNIV. OF HAMBURG

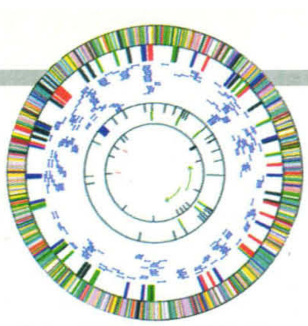
High profile. The Visible Human goes on-line.

This year, biologists began browsing a federation of linked databases, clicking from gene sequence to protein structure to journal article; the number of entries in one such database, GenBank, more than doubled in 1995. Electronic publications multiplied, while traditional journals plunged into cyberspace. For example, astronomers put *The Astrophysical Journal Letters* completely on-line and linked it to a literature database, so astronomers can click on references and see abstracts or full texts—30 days ahead of the print version.

Also in 1995, students around the world signed up for one of the first electronic courses, on protein structure. And the Visible Human project rendered anatomy not only visible but workable, with a library of detailed computerized tomography and magnetic resonance imaging (MRI) scans of male and female cadavers available on-line or on CD-ROM. This year, such technologies not only provided speedy answers to scientific queries; they broadened the universe of possible questions.

A. R. KERLAVAGE

The little genomes that could. Could be sequenced, that is. Despite skepticism from colleagues in academia and government, in 1995 private sector geneticists showed that they had what it takes to sequence not one, but two entire bacterial genomes.



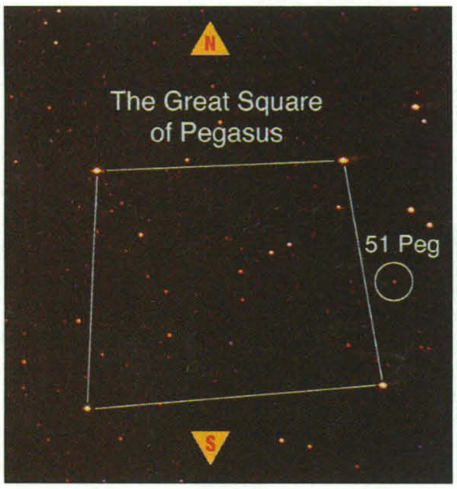
Sequencing star. This entire bacterial genome was sequenced.

Thanks in part to sophisticated computing abilities, in July researchers at a not-for-profit research institute reported the full DNA sequence of the 1.8 megabase *Haemophilus influenzae*; in October they published the 0.6 megabase *Mycoplasma genitalium*. A handful of tiny viral genomes had been sequenced before, but viruses grow and reproduce only with the help of the cells they infect. In contrast, the two bacterial genomes contain all the information needed to sustain life, and so may help answer questions in arenas ranging from bacterial evolution to human disease.

Progress in this field has been so rapid that sequencing the whole genomes of simple prokaryotes will soon be routine. Indeed, in 1996 geneticists expect to complete the full DNA sequences of at least six more bacteria. And a collaboration of mainly European geneticists anticipates passing another milestone in early 1996: the first complete sequence of a eukaryote, the 12.5 megabase yeast *Saccharomyces cerevisiae*. If all this wasn't enough, on page 1945 of this issue, researchers present a physical map of the human genome containing nearly 14,000 markers. Their work will help speed the mammoth task of sequencing all of the genome's 3 billion bases, and provides a fitting end to a year of dramatic sequencing achievements.

News from another planet. Astronomers have long looked for planets outside our solar system, but seeing one in the vastness of space is akin to locating a black-clad ballroom dancer in a dimly-lit hall. So a Swiss team scanned the skies for the movements of their quarry's brightly gowned celestial partner—a star. In 1995, this strategy was a smashing success: In the constellation Pegasus, they made the first likely detection of a planet orbiting a sunlike star.

The team monitored the stars for a slight wobble that would signal a planet whirling in a star's gravitational embrace. Their new-found planet, a giant at least half the size of Jupiter, gyrates around a star called 51 Pegasi. Astronomers were further amazed by the planet's position. Theory predicts that large planets should form relatively far from a star, about where Jupiter and Saturn did in our own solar system. But with an orbital period of just 4.2 days, the putative planet must be twirling virtually cheek-to-cheek with its stellar companion, separated from it by just one sixth the distance between our sun and Mercury.

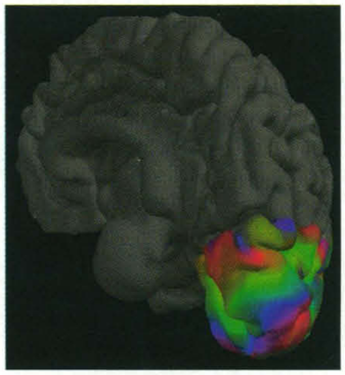


JIM SEEVERS/ADLER PLANETARIUM & ASTRONOMY MUSEUM

Planet spotting. Astronomers found evidence of a new planet orbiting 51 Pegasi.

Although other groups quickly confirmed the data, some astronomers cautioned that the star's perceived wobble could be due to other causes. In any case, expect 51 Peg's swaying dance steps to be in the astronomical spotlight for some time to come.

The mind at work. In 1995, new techniques for imaging the human brain helped unify studies of the mind and brain. In years past, neurophysiologists studying the brain gathered data by poking electrodes into the brains of experimental animals, while psychologists and psychiatrists studying the human mind treated the brain largely as a black box. Brain imaging has recently opened the lid of that box, allowing scientists of many disciplines to peer inside. This year saw advances in noninvasive imaging techniques such as functional MRI (fMRI) and magnetoencephalograms, which allow researchers to observe neural activity in living humans with ever-increasing precision.



M. SERENO *ET AL.*

Showy image. Researchers watched the visual cortex light up.

In 1995, researchers used fMRI to make detailed maps of the human brain, delineating to the millimeter the areas devoted to vision and to movement. Their new map of the motor area revised old notions that this part of the brain contains a point-to-point blueprint of the body parts it governs. Other studies this year explored uniquely human traits such as language and musical talent. One study confirmed that women use both sides of their brains in processing language while men rely chiefly on the left brain; another uncovered an unusual asymmetry in the auditory cortex of musicians with perfect pitch.

Work this year also let scientists spy on learning itself. One group saw changes in the motor cortex as subjects learned a finger-tapping sequence; another watched the effects of learning in string musicians. In 1996, expect imaging to continue to bridge the gap between mind and brain.

Droplets in the greenhouse. What a difference a micron can make. According to scientists' best theory, the inexorably increasing greenhouse gases in Earth's atmosphere should have been warming the globe for the past century. But for years, climate researchers couldn't find the warming signal they expected. In 1995, they finally recognized the effect of greenhouse gases amid the clamor of natural climate variations—and concluded that human activities are indeed heating up the planet.

The trick, it turned out, was allowing for the cooling effect of what individually are inconsequential droplets of sulfuric acid, which are ultimately derived from the burning of fossil fuels. In huge numbers, these microscopic droplets form an aerosol haze that has shaded much of eastern North America, Europe, and south Asia. That shading has been moderating greenhouse warming and disguising the warming's telltale geographic "fingerprint." By explicitly including the effects of aerosols in their models, researchers could finally identify that fingerprint.

As a result, the United Nations–sponsored Intergovernmental Panel on Climate Change has officially concluded that the greenhouse effect is behind some of the observed warming. Thanks to an appreciation of micrometer-size particles, politicians must now seriously consider what should be done about a truly global problem.

Skinny gene, fat investments. Late last fall, researchers at Rockefeller University cloned a gene called *obese*—and started a near-riot on Wall Street. Americans spend $30 billion a year on weight-loss schemes, so biotech companies and their investors were eager for research that could lead to a treatment for obesity. The mutant form of *obese* produces grossly fat mice, and the companies hoped that the gene's normal protein product, called Leptin, might one day help humans lose weight. In March, Amgen Inc. won the bidding war for the exclusive right to develop products based on *obese*. They paid $20 million—the most ever paid upfront to a university for a patent license.

FRIEDMAN *ET AL.*

That investment hasn't paid off yet, but this year researchers took the next step, showing that fat mice injected with Leptin lose weight. Even normal-weight mice treated with Leptin shed fat. Don't go running to your pharmacist yet—Leptin hasn't been tried in humans. But it's currently being tested in preclinical animal safety trials.

The companies that lost out on Leptin itself are still racing to find its receptor, which is not covered under the *obese* patent. This year, researchers found that in mice, Leptin binds to a part of the brain called the hypothalamus, making this region a likely site for the receptor. Undoubtedly Wall Street has taken notice.

A time for telomeres. The telomeres, the specialized structures at the ends of chromosomes, were originally known only from studies of single-celled protozoans. But a few years ago, they leaped into prominence as a result of evidence suggesting that in higher organisms they normally play a role in controlling cell aging, and when that goes awry, in cancer development. This year, researchers took another big step toward understanding telomeres by isolating components of telomerase, the enzyme that synthesizes them.

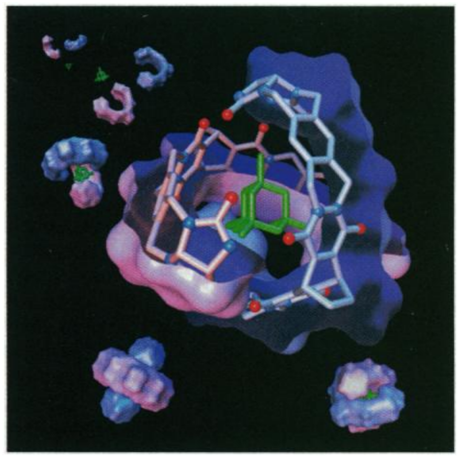
Telomerase is unusual because it includes an RNA, which serves as a template for telomere synthesis, in addition to the protein that actually accomplishes the synthesis. Until recently, cell biologists had been able to isolate only the RNA, and only from protozoa. But in 1994, researchers isolated telomerase RNA from yeast, and this year they captured both the human and mouse RNAs. They also picked up the first telomerase proteins, which came from a protozoan, and a possible yeast telomerase protein. The hope is that this will open the door to isolating these proteins from higher organisms too.

Because abnormal activation of telomerase may contribute to cancer development, cancer researchers are racing to study these newly revealed molecules as potential targets of chemotherapy. So despite the humble beginnings of telomeres, research on the structures may one day yield important clinical benefits.

Molecular self-starters. Chemists traditionally forge molecules in materials with extreme conditions of temperature and pressure, but nature builds many structures by selecting precise molecular components and allowing them to weave themselves together. This year, scientists mimicked nature, harnessing the weak forces among molecules to create a host of their own self-assembled structures.

In 1995, researchers used bench-top techniques of self-assembly to make patterns on semiconductor surfaces; this opens the door to cheaper microelectronics and optoelectronics, made without clean rooms or lithography. Researchers also used self-assembly to organize minute particles of semiconductors and metals known as quantum dots, continuing the push to a new era of molecule-by-molecule materials synthesis.

Also this year, chemists built large molecular capsules able to stitch themselves together around chemical cargo. They filled these molecular wiffle balls with benzene and other small molecules, a trick that may eventually be useful for drug delivery. Other self-assembled creations include molecular sensors that change color when they bind to their target. Watch for more self-assembled molecular marvels as researchers continue to imitate nature's building techniques.



MICHAEL PIQUE/THE SCRIPPS RESEARCH INSTITUTE

Self-construction. Chemists designed self-assembling structures to carry molecular cargo.

–The News and Editorial Staffs

For an expanded version of this section, with references and hot links, see Science On-Line *at* <http://science-mag.aaas.org/science>.

Biggest Molecule: Titanic Titin

In 1995 biologists smashed records by cloning the DNA for the largest protein molecule known. The aptly named titin weighs in at a molecular weight of 3 million and consists of a continuous chain of 27,000 amino acids, making it 20 to 50 times larger than the average-size protein.

Like the Titans of Greek mythology, titin is known not only for its size but for its strength. Each molecule spans a distance of 1 micrometer and acts as a microscopic spring that pulls a muscle fiber back into shape after it is stretched.

Global Budget Battles

Chronic worry over funding is an occupational hazard of basic research. But in 1995 fiscal anxiety reached new heights, as scientists around the world saw traditional funding sources shift priorities or even dry up altogether. Yet despite the apprehension, much research in the United States and Europe managed to elude the budget-cutter's ax—for this year, at least. And while American technology programs took a big hit, other nations made applied research a winner.

In the United States, a new Congress eager to slash spending took a hard look at science, and protracted wrangling over the 1996 budget left plenty of time for worry. Nearly a quarter of the way into the new fiscal year, Congress and the White House were still arguing over spending bills, including those that fund most academic research. Indications are, though, that the budgets of the National Institutes of Health and the National Science Foundation will weather the storm for now, and basic research at the Department of Energy survived relatively intact. But some government-funded applied research efforts face elimination, including the Commerce Department's Advanced Technology Program. Even advice was deemed expendable, as Congress axed its own 23-year-old Office of Technology Assessment.

The balanced-budget fever has struck Europe too, and many nations such as France and Germany gave science and technology flat funding. And one of the chief sources of funding for scientists in Russia and other nations of the former Soviet Union, the International Science Foundation, all but emptied its $129 million war chest this year.

But there were bright spots too. For example, the European Union's main funding program, Framework IV, is providing almost twice as much as previous frameworks, $15.5 billion for the period 1994 to 1998. This program explicitly aims to make industry more internationally competitive, spelling good news for areas such as telecommunications. Also this year, the United Kingdom completed a massive consultation exercise, known as the foresight program, to identify technologies that may one day create wealth. So far, only a small sum for foresight priorities has been factored into the funding equation, but U.K. researchers worry that in the long term, the exercise may steer funds away from curiosity-driven research.

Meanwhile, both Europeans and Americans may look eastward with envy. In Japan, 4 years of recession have provided an unexpected boon for government-funded research. To stimulate the economy, the government approved two whopping spending packages—and spread the largess to science, boosting government research budgets by over 10%.

In the United States and elsewhere, scientists are already gearing up for the next round of justifying their efforts. But for those whose programs escaped cuts, it's achievement enough to know that they survived '95.