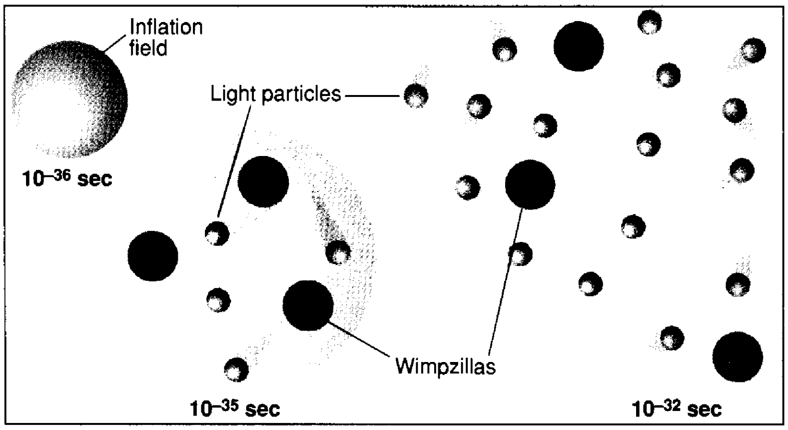
zillas could be millions to trillions of times more massive than Wimps and would have been created even earlier in the mayhem of the big bang. Their large mass means that relatively few of them could account for most of the weight of the universe. "Size does matter," growls Rocky Kolb of the Fermi National Accelerator Laboratory and the University of Chicago, who presented the work for a team of theorists.



Wimpzillas weigh in. These hypothetical particles would form in the universe's earliest moments, as it grew from grapefruit-size (10^{-36} seconds) to basketball-size and beyond.

Wimpzillas are as much a figment of theory as their lighter cousins, but for some theorists they're an especially welcome one. They could turn out to be the very same particles that are the linchpins of an effort to explain all the forces of nature in a single framework—a so-called grand unified theory (GUT) —put forth in 1990 by John Ellis of CERN in Geneva, Switzerland, Dimitri Nanopoulos of Texas A&M University, and others. And debris thrown off by Wimpzillas when they decay, as the GUT predicts, might explain the rare, mysterious cosmic rays that slam into Earth's atmosphere at astonishingly high energies (*Science*, 1 September 1995, p. 1221and 22 December 1995, p. 1923). Nanopoulos says Wimpzillas have him so excited, "I am almost getting white hair."

The monster particles emerge naturally in cosmologists' standard creation story, says Kolb. The story begins when the tiniest mote of the primordial emptiness happens to pop into a state called a "false vacuum," setting loose a tremendous, exponential expansion. The false vacuum has more energy in it than ordinary emptiness, and according to Einstein's equations of relativity, this energy acts like gravity thrown into reverse, driving the expansion—a runaway process called inflation.

Inflation goes on for 10^{-35} second or so, creating more and more space filled with false vacuum—and nothing else. "There's no radiation. No matter. No House managers. It's a good universe," says Kolb, in one of the symposium's many tilts at the impeachment proceedings then playing out in Washington. The chilly symmetry of the false vacuum somehow shatters at about 10^{-35} second, ending the era of exponential expansion. Its energy is converted into an outrushing fireball of particles and radiation—the start of the big bang.

The heat of that fireball could have gone into creating ordinary Wimps, with masses as high as a million times the mass of the proton (10^6 giga-electron volts, or GeV). They would have been spawned as particles of both matter and antimatter, which would annihilate each other when they meet. But the weak attractions between Wimps and the continued expansion of the universe, which would have swept some Wimps out of harm's way, could have ensured enough survivors to account for the large fraction of cosmic mass—up to 90%—thought to be dark matter.

But now Kolb and his collaborators Antonio Riotto of CERN and Daniel J. H. Chung of the University of Michigan, Ann Arbor, have come up with the heavyweight challenger. Following an example set by Andrei Linde of Stanford University, Lev Kofman of the Canadian Institute for Theoretical Astrophysics at the University of Toronto, Alexei Starobinsky of the Landau Institute in Moscow, and others, they began eyeing the instants just after inflation and before the main fireball, when higher energies—and, hence, higher masses—might be available.

"All of a sudden we have found that this is a pretty rich physics regime," says Linde—and a rich source of particles. Riotto says that he, Kolb, and Chung soon found several ways to produce superheavy particles. The trio's favorite relies on the pairs of virtual particles that pop in and out of existence in any vacuum, according to quantum mechanics. The "reverse gravity" still in effect at the end of inflation rips any such pair apart, so that instead of meeting up, annihilating, and disappearing, the particles take on a real existence. The Wimpzillas would have been scarce enough to avoid meeting each other and annihilating when expansion slows in the later fireball.

Such particles could be as heavy as 10^{13} GeV—femtograms, a mass normally in the domain of high-resolution chemistry, not particle physics—so just a smattering of them could account for dark matter. And since annihilation is never a threat, intrinsically weak interactions are not required. "Wimpzillas might be charged," Riotto says. "They might also have strong interactions."

But it's a weakly interacting Wimpzilla around 10^{12} GeV that interests Nanopoulos, because his and Ellis's so-called "flipped SU(5)" GUT long ago predicted a heavy analogue to the proton at about that mass. Their theory predicts that such a particle, which they called a crypton, should decay after a long but finite lifetime, flinging off particles that could slam into Earth's atmosphere as ultrahigh-energy cosmic rays.

While the new calculations have delighted some researchers, they have hit others like a punch in the stomach. Wimps fit naturally into a less ambitious particle theory called supersymmetry, which many physicists favor. Observers might also be feeling queasy, since if rare, lumbering Wimpzillas make up the dark matter, then current Wimp searches (*Science*, 1 January, p. 13) would have no hope of turning up a signal unless the universe is populated by an even more bizarre mixture of the two particles. And it's only getting worse. Linde and colleagues, for example, say they might have found a way to make relics as heavy as 10^{18} GeV. Says Linde, "We call our particles fat Wimpzillas."

–JAMES GLANZ

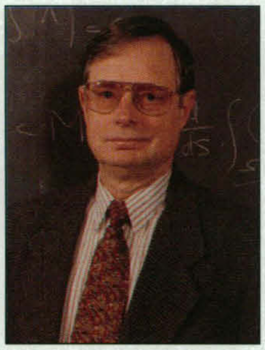
FEDERAL RESEARCH

Efforts to Evaluate R&D Found Wanting

Follow the rules, work together, use outside experts—and don't neglect the young ones. That's the message from a National Academy of Sciences (NAS) panel asked to help federal agencies evaluate their R&D efforts as part of a 1993 law that many research officials have sought help in implementing.

The Government Performance and Results Act (GPRA) requires every federal agency, starting this year, to link its budget to its program goals and explain how it plans to measure progress toward those goals. The exercise has challenged officials at agencies, such as the National Science Foundation (NSF) and the National Institutes of Health (NIH), which support basic research that often may take decades to generate any social or economic payoff. Some officials and scientists have argued that any evaluation is doomed to fail or—worse—that it will force agencies to emphasize trivial results that can be easily quantified.

Nonsense, says the Committee on Science, Engineering, and Public Policy (COSEPUP), a joint panel of NAS, the National Academy of Engineering, and the Institute of Medicine. "Both applied and basic research programs can be evaluated meaningfully, and on a regular basis," concludes the panel in a report issued on 17 February, for which six federal agencies anted up $300,000. The tricky part is devising the right yardsticks, says the panel, chaired by Phillip Griffiths, director of the Institute for Advanced Study in Princeton.



Outside advice. Phillip Griffiths heads COSEPUP.

The panel, which met with agency officials after they had prepared their first performance plans to accompany last year's budget request, endorses the use of outside experts. It would be an expanded form of the peer review process that judges individual proposals, with reviewers looking at the quality and relevance of an agency's entire research portfolio. "The research needs to be done well, worth doing, and able to stand up to international comparisons," says panelist Morris Tanenbaum, a former chair of AT&T Communications. The report suggests that one agency serve as a focus for research supported by many agencies, such as global change or information technology, to make sure that national goals are also being addressed. In particular, the report notes that most R&D agencies played down their training roles when writing up their plans. "The defense and energy departments train the majority of engineers and physical scientists in this country, but those agencies are downsizing and nobody's picking up the slack even though there is heavy demand by industry in some sectors," complains panelist Mildred Dresselhaus of the Massachusetts Institute of Technology.

Academy officials would like to follow up this week's report with a longer study that Congress proposed in legislation passed last fall. It invites the Office of Science and Technology Policy (OSTP) to contract with the Academy "to develop methods for evaluating research programs," including knowing when to pull the plug. The exercise is also contained in a Senate bill (S. 296) that would double federal R&D spending by 2010.

The study has been blocked by White House objections, however. In a 7 October letter to the Senate Commerce Committee, OSTP Director Neal Lane explained that the Results Act already "provides the correct framework for developing performance goals for federal [R&D] activities" and that the new study "would depart from the GPRA approach by mandating alternative forms of evaluation." Agencies can now request permission to use nonquantitative measures, but some Administration officials see the proposal as an attempt to skirt the current law by substituting Academy criteria for those approved by the White House.

Not so, says Michael Lubell of the American Physical Society, one of many professional organizations lobbying hard for the measure. "The Academy study would provide additional options for evaluating research in a way that Congress could use to judge the success or failure of programs," he says. "Nobody wants to scrap GPRA, but scientists tend to worry when somebody other than an expert in the field tries to judge the quality of their work."

–JEFFREY MERVIS

* Evaluating Federal Research Programs www.nas.edu

COMPUTER SCIENCE

New Interface Makes Virtual World Tangible

When you explore or manipulate an object in the real world, it helps to use your hands as well as your eyes. Handling a flexible plastic film, for example, requires sensing small pressure variations across the finger tip. Inserting a pin into a small hole can require real-time information about friction and vibration. In the virtual world of computer models and remote-control robots, users generally lack such tactile, or haptic, feedback, which makes delicate manipulative tasks even more difficult. Now physicist Ralph Hollis and graduate student Peter Berkelman, of Carnegie Mellon University's Robotics Institute in Pittsburgh, have developed a new way to bring the sense of touch to computer interfaces: a magnetically suspended joystick that allows a user to manipulate—and feel—objects in the virtual world.

It's not the first haptic interface ever constructed, but it is the first to rely on magnetic levitation instead of conventional bearings, which eliminates friction and allows the device to reproduce more subtle tactile feedbacks. "It's quite an impressive interface," says haptics researcher Edward Colgate of Northwestern University, who tested the device when it was unveiled last November at a haptics symposium.* "You get the complete sensation of both motion and physical interaction in a very real way." Next May, the device will be shown in action at a robotics conference in Detroit.

It works by harnessing the Lorentz force, an effect discovered in the 19th century in which a wire carrying an electric current and immersed in a magnetic field experiences a force at right angles to both the current and the magnetic field. The force can be used to suspend a current-carrying object between two magnets—what Hollis calls Lorentz levitation. It can also cause the suspended object to move when the current flowing through it is changed.

Hollis reasoned that the right arrangement of magnets and current-carrying coils could generate force feedbacks that a user grasping the suspended object would sense, and he thought it could lead to a more realistic haptic interface than ones based on motors, wires, and pulleys. "In general, these types of devices haven't been able to achieve the degrees of freedom needed to manipulate an object's motion in space and they have too much friction, which doesn't allow the user to feel anything but the biggest haptic sensations," says Hollis.

To put theory into practice, the Carnegie Mellon group built a device consisting of a joystick handle attached to a bowl-shaped nonmagnetic surface that contains six wire coils. This assembly, called the flotor, is suspended in the air gap between six pairs of permanent magnets mounted inside and outside the flotor on bowl-shaped stationary surfaces. An arrangement of three light-emitting diodes (LEDs) and matching optical position sensors allows the device to sense motion in the flotor.

See me, feel me. An arrangement of magnets and coils creates a computer interface that can generate tactile feedback.

When an operator moves the joystick, each LED-sensor pair records movement in both the x- and y-axes around that sensor. Combining the output of the three pairs gives six independent measures of movement, corresponding to the six degrees of freedom—x, y, and z, plus pitch, roll, and yaw—needed to describe the motion of any object manipulated in space. Software, analogous to but far more complicated than the device drivers used to translate the motion of a trackball to movement of the cursor on a computer screen, translates the sensors' electrical output into movement of an object in a

* 17th annual Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems, sponsored by the American Society of Mechanical Engineers, Anaheim, California, 19 to 20 November 1998.

CREDITS: (TOP) RANDALL HAGADORN/INSTITUTE FOR ADVANCED STUDY; (BOTTOM) PETER J. BERKELMAN