symmetry

dimensions of particle physics

A joint Fermilab/SLAC publication

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On the Cover
Physicist-photographer David Kirkby whimsically interpreted the concept of dark matter by showing this typewriter key, flipped for clarity. It represents the roughly 5 percent of the universe that is visible matter on a background of dark matter and dark energy, which are both still very mysterious. However, physicists do know how these components come together consistently in the "concordance model" of cosmology, as discussed in this issue of *symmetry*.

Photo courtesy of David Kirkby

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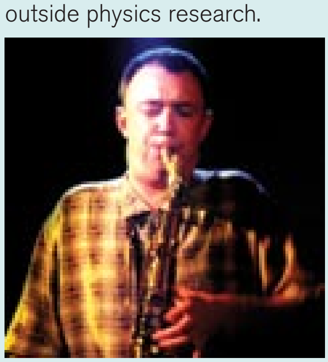

Office of Science
U.S. Department of Energy

Photo: Reidar Hahn, Fermilab

Appreciating successes

Science is a forward-thinking endeavor: It is more concerned with what can be discovered in the future than what has been learned in the past. Once accomplished, successes are usually taken for granted.

Sometimes it is worth stepping back to reconsider achievements. This is especially true for the proposed International Linear Collider. While much attention and discussion is focused on when, where, and how this machine could be built, it is easy to forget the ILC progress achieved so far.

The first milestone, the 2004 choice of acceleration technology, could have split the particle physics community and derailed the ILC. However, strong leaders eased the way through a difficult and complex global decision-making process to begin a unified R&D effort.

The 2007 release of the ILC *Reference Design Report* is another milestone (see story on page 10). Arriving at this point in ILC planning has taken many thousands of person-years of effort. Yet most of the design process is invisible to people outside the enterprise; they often don't appreciate just how much thought and effort has to go into preparing a plan for a large scientific facility, even before any decision to proceed is made. For their effort, we congratulate Barry Barish and all people involved in advancing the ILC.

Meanwhile, particle astrophysicists and cosmologists are intensely interested in dark energy and dark matter. They are discussing a suite of possible future observations and experiments. But dark energy and dark matter are so much more than a mystery to be explored: Their existence already solves a vast number of problems that cosmologists were facing, an achievement that is often overlooked.

The "concordance model" of cosmology, which incorporates visible matter, dark matter, and dark energy in just the right mix, brings a coherent outline to physicists' understanding of the universe (see page 16). It has unified cosmology just as the Standard Model unified particle physics.

Physicists don't dwell on their successes; they quickly move on and keep exploring and discovering. As you read this issue, take a moment to appreciate the extraordinary successes of physics research and how they enliven our world.

David Harris, Editor-in-chief

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Photo: Reidar Hahn, Fermilab

Focus on the Future

Over the next few years, the United States and the international high-energy physics communities will see great scientific opportunities and profound changes. These, in turn, will pose profound challenges. We must make the right choices on the right timescales to ensure the vitality and continuity of the field of elementary particle physics for the next several decades and to maximize the potential for major discovery throughout that period.

Three events are notable:

- Within the next several years, the US accelerator-based program will complete two highly successful experimental campaigns—the Tevatron at Fermilab and the *B* Factory at SLAC. These two accelerators are making very significant advances in the field, and I congratulate the teams at both facilities for their achievements to date and for their success in running these accelerators far above their original design luminosities.
- Second, in the next year the Large Hadron Collider at CERN is scheduled to commence operations, opening wide the door to physics at Terascale energies and ushering in a period of new and exciting scientific opportunity.
- Finally, the Global Design Effort (GDE) recently released a reference design for the International Linear Collider (ILC)—a machine that through its power, precision, and clarity holds great promise for deepening our insight into the mysteries of the universe.

Many individuals and many groups already have given considerable thought and effort to the path forward in high-energy physics. The EPP2010 National Academy Report of April 2006 and the October 2006 Particle Physics Project Prioritization Panel (P5) Roadmap Report articulate a broad set of scientific opportunities and compelling priorities: the highest priority is to go to the Terascale. Given the high stakes—the risks and the rewards of various paths—I welcome the opportunity to work with the high-energy physics community on the future of the field.

The Department of Energy (DOE) is committed to working as an international partner on the R&D for the ILC. Let us make no mistake about the magnitude of such an effort: the path to possible deployment of the ILC will take time. The GDE suggests the R&D alone could take three to five years. In addition, because the ILC will be international, at some point it is necessary to put together a government organization of funding states. This is no small task, as the ITER negotiations demonstrated. It took three years to conclude these negotiations, and that for a facility for which the engineering drawings and cost estimates were firm. Finally, the future of accelerator research and operations at Fermilab needs to extend to the construction phase to keep the United States competitive for the proposed ILC. The DOE position is that we must "keep the door open" by having a competitive high-energy accelerator physics program at Fermilab, capable of being the site for the ILC. All these conditions require a concerted effort to map out detailed projections of international arrangements (R&D), the nature of the international organization of governments, and a vibrant future for Fermilab and the high-energy physics community within the United States.

Within this context, it is important that the High Energy Physics Advisory Panel focus on the future of elementary particle physics. If the ILC were not to turn on until the middle or end of the 2020s, what are the right choices to ensure the vitality and continuity of the field during the next two to three decades and to maximize the potential for major discovery during that period? Given the technological and resource challenges involved, the high-energy physics community must develop a sufficiently compelling scientific rationale, outline a credible path forward, and mobilize a coherent national effort on a scale that would ultimately be necessary for a facility investment of this scope.

Since World War II, the United States has had a leadership role in high-energy physics, and we at DOE are committed to maintaining US leadership in this field.

Raymond L. Orbach

Raymond L. Orbach is Under Secretary for Science at the US Department of Energy.

Too famous for acknowledgement; filming a *Star Wars* fan-film at Fermilab; when waiters are physics fans; learning cyber-security through hacking; accelerator at the fair; letters: magnets, mystery ice, and marriages.

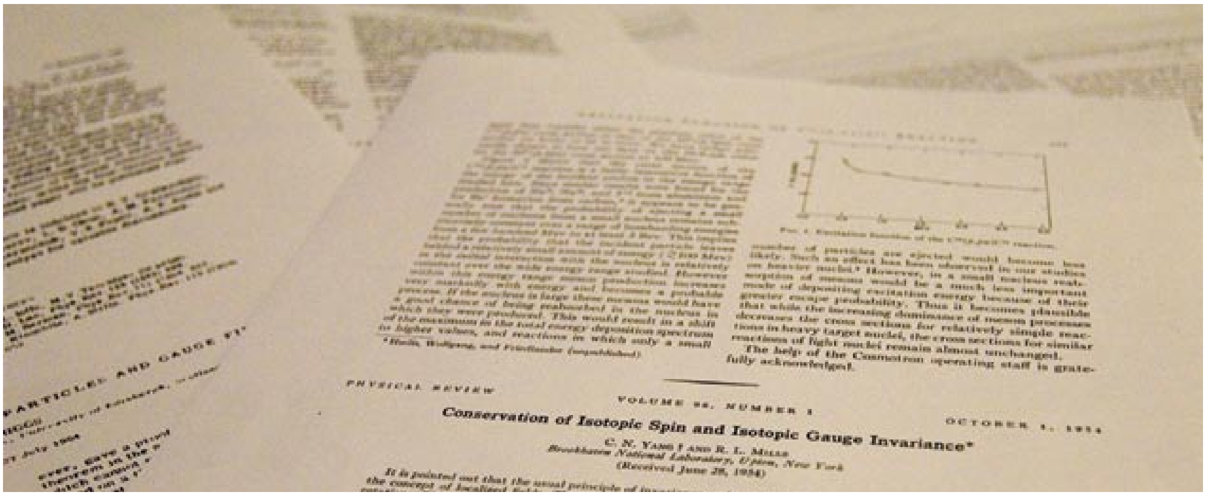


Photo: Sandbox Studio

Name of fame

Counting the number of citations of a particular paper is one way to measure its impact and importance. But it is by no means the only gauge. Ettore Majorana's famous paper, "Theory of the symmetry of electrons and positrons," has only 154 citations in the SPIRES database, yet physicists around the world have heard about Majorana neutrinos. The titles of more than 700 scientific articles mention the name Majorana! Yet the vast majority of these articles do not cite the original work.

Majorana's case is not an exception. From Yang-Mills equations to the Schwarzschild radius, the ground-breaking work by many physicists has been honored by associating their name with a discovery. Yet the number of citations of their papers is not keeping up with their fame. Yang-Mills is mentioned in the titles of almost 4500 papers, yet the original article has fewer than 1200 citations. Schwarzschild gets mentioned 750 times in titles, but none of his papers has more than 40 citations.

The ultimate name of fame might belong to physicist Peter Higgs. Three of his papers have about 1000 citations each. Yet the titles of 7500 papers mention the name Higgs—not counting the numerous popular science articles on the Higgs boson. That's a name of fame that even Albert Einstein cannot keep up with. His name appears in the titles of "only" 3000 papers in the SPIRES database.

Heath O'Connell, Fermilab

Star Wars lands at Fermilab

Fermilab physicist Darren Crawford shares a birthdate, May 25, with the first *Star Wars* movie release. Now he is making his own mark on the fabled sci-fi fantasy series. Crawford is producing a *Star Wars* fan movie and plans to shoot scenes at Fermilab this spring. "I've already scouted some spots," says Crawford. "A lot of *Star Wars* characters will be wander-ing around for a few days."

Crawford is writing, casting, shooting, directing, and editing the 2 1/2-hour film, *Star Wars Forgotten Realm*. The story fits into the *Star Wars* timeline between Episode 3 and Episode 4, at the start of the rebellion against the Empire. "Two rebels are shot down on a planet and they come across a Jedi who has been stranded there for years," says Crawford. "The Empire finds the Jedi, and Darth Vader confronts him."

Crawford says he knew the film would work the moment a local fan arrived to audition for the part of Darth Vader. "He was about 6'5" and he had

Parody: Sandbox Studio

the fiberglass helmet…the whole thing," says Crawford. "His reading just blew me away." In addition to hundreds of other local actors and family members (Crawford's six-year-old daughter will play the young Princess Leia), nine Accelerator Division employees will act, provide music, create computer-generated special effects, and construct the sets. Fermilab's Bruce Worthel, who is trained in martial arts, will provide light-saber choreography.

Like other fan projects, *Forgotten Realm* benefits from the goodwill of George Lucas, *Star Wars* director and executive producer. He encourages fans to contribute their own stories as long as they don't make money using the *Star Wars* trademark.

Crawford doesn't mind having to pay for his film project out of his own pocket.

"I've wanted to do this for years," says Crawford. "That first day, when everyone was assembled…it was like a feeling of euphoria."

Siri Steiner

"Soup, salad, or Higgs?"

A snowstorm hit the Chicago area on February 13, before the start of the DOE/NSF agency review at Fermilab of the US ATLAS and US CMS collaborations, the US contributions to two of the Large Hadron Collider experiments. A number of people were trying to fly in—both reviewers and reviewees—and we got started late that evening with only some of the people attending. Our dinner plans also fell through, so at the suggestion of DOE reviewer Pepin Carolan, we went to a restaurant called Riva's in nearby Naperville with a few people willing to brave the weather: Carolan and Saul Gonzalez of DOE, Joel Butler of US CMS, and myself.

At Riva's, we encountered a huge panoramic painting of the Chicago skyline, done by a local artist, and several monitor screens displaying stock information and business news. And then we encountered Dave the Waiter. It was pretty quiet in the restaurant, and Dave asked us what we were doing out on that stormy night. We told him we were at Fermilab for a review, and that got him going at high energy.

He asked whether Fermilab would discover the Higgs. He asked about new results from the lab with Higgs indications at around 160 GeV. He knew about CERN and the LHC. We told him we needed him on one of our reviews. He was better informed than some of our colleagues.

Dave the Waiter made our day, given all the weather problems and all our difficulties getting the review started.

Michael Tuts, Nevis Labs, Columbia University, DZero experiment at Fermilab

Photo: Fred Ullrich, Fermilab

Expert "hackers" challenge students

Tim Rupp and Joe Klemencic, two of Fermilab's computer security wizards, posed as the bad guys to offer a challenge in the Indiana state-wide college cyber defense competition held at Indiana Tech. With their role-playing, Klemencic and Rupp helped to educate the tech-savvy students about what motivates the enemy.

Sponsored by the National Science Foundation, the competition pits top students in computer science programs against would-be hackers to teach them about business security in a realistic environment. During the two days of the competition, the college teams completed business tasks sent to them by a White Team, representing managers, while fending off attacks from a Red Team, portraying hackers.

At Indiana Tech, teams from IT and Ivy Tech Community College set up simulated business environments in networked classrooms. From another classroom, the Red Team, consisting of Klemencic, Rupp, and the personal computers they'd lugged from home, tried to break into their computers. Because the teams focused most of their energy on preserving their computing infrastructure and resources, the Red Team successfully compromised their systems, says Klemencic. Unbeknownst to the students, they accessed the teams' web servers and personal data, such as usernames and passwords.

In a debriefing session on the final day of the competition, Klemencic and Rupp disclosed their strategies and tools to the surprised teams. "We had to drive into them that the bad guys aren't out to ruin their systems," says Rupp. "It's money that drives them. Systems can be replaced, but once data is lost, you can't get it back."

Rupp participated in the competition last year as a senior on IT's team. He did several summer internships at Fermilab before graduating and coming to work for the Computing Division in June 2006. Although his team lost the 2006 competition by only a fraction of a point, he's learned from Joe to keep on top of current hacker technology. "We talk all day long about new exploits that are coming," he says.

Christine Buckley

Letters

Marvelous engineering

The article on Fermi's magnet (*symmetry*, Dec 2006) included the quote, "When it became superconducting, it was ugly and took weeks and weeks to come online." This quote is not accurate and takes away from the marvelous achievement of converting the Chicago Cyclotron Magnet (CCM) from normal conducting to superconducting. The work done by Eddie Leung, Howard Hart, Gene Smith, and the whole Lab 3 team in Research Services deserves proper recognition.

Although it is correct that it took a week or so to cool such a large magnet down, powering it took less than one hour. The conversion saved an order of magnitude in the 2 MW electrical power consumption of the magnet (taking into account the power needed for helium refrigeration and buss work). Despite its huge size, the CCM in operation had a smaller heat leak than a single superconducting dipole magnet in the Tevatron collider. This was true despite the 1.2 million pounds of force attracting each coil to the iron yoke when excited. There was some excellent Fermilab engineering in that magnet!

Bob Kephart, Fermilab

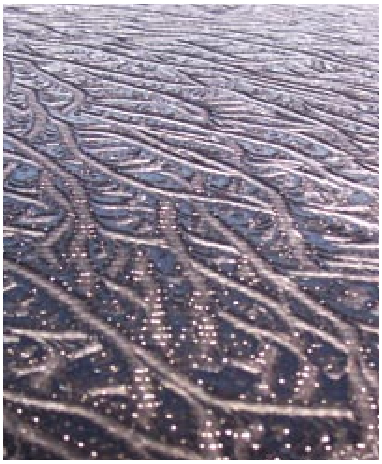


Photo: Terry Anderson

Aliens?

This photo was taken in Campbell, California, February 23, 2007, 7:20 a.m. Subject matter was a 2000 Honda Accord sunroof. Car was facing due north, half a tank of gas, and 36 lbs of air pressure in 3 of the 4 tires. AccuWeather says the coldest temperature during the night was 34 degrees Fahrenheit. Wind speed was 1-5 mph out of the NW and the relative humidity was in the low 90s with no measurable precipitation.

I often have a layer of frost on my car during the colder days of winter but have never seen anything like this. Can anyone explain how these strange patterns were etched in ice on the roof of my car?

Terry Anderson, SLAC

Physics bliss

It was very nice reading the article on couples in physics in the January/February issue of *symmetry*. Satyajit Behari and I are also physicists happily married to physics, and have been working together at Fermilab since 2000. Satyajit has been working on analyses within the *B* physics group. He was heavily involved in the CDF Run IIb silicon upgrade project and currently is one of the on-call experts for the CDF experiment providing silicon detector maintenance and running. I was previously at CDF (1999-2003), and I have been at DZero since 2004, also working on analyses in the *B* physics group. A precious gem in our life, our daughter Barnali, was born in 2002. She attends the Fermilab daycare center and will be 5 years old this month. We were heartened to see the stories of others who are happily married, and happily married to physics.

Tania Moulik, Fermilab

Fermilab fleece

I thought it might amuse you to know that I've spotted a Fermilab full-zippered fleece in the *Concord Monitor*.

The story is an account of a lecture given in Concord, New Hampshire, by Brother Guy Consolmagno of the Vatican Observatory. The story is accompanied by a photo of Guy, who has given a colloquium at Fermilab ("Visitors from Another World: Searching for Meteorites in Antarctica," April 1998) and visited on several other occasions, wearing his Fermilab fleece jacket.

Guy is the author of *Brother Astronomer*, and co-author of the popular *Turn Left at Orion*, a guide to using a small telescope. He also has a new book coming out in the fall.

I don't suppose that Jesuit astronomers are fashion trendsetters, but it's still nice to see the Fermilab logo turn up in an unexpected place.

Bill Higgins, Fermilab

BNL job bank

The commentary by Marc Sher on "The two-body opportunity" (Dec 2006) highlights both the problem of finding suitable positions for dual-career couples in physics and the advantages of hiring them together. Indeed, his comments are true for couples in any scientific discipline. To make finding positions easier for couples in the sciences, Brookhaven National Laboratory has become one of the founding members of a new job bank that will facilitate dual-career appointments.

In February, Brookhaven Lab joined the Metropolitan New York and Southern Connecticut

Higher Education Recruitment Consortium (HERC). The HERC website, a collaborative effort developed by Columbia University, Yale University, and New York University, is meant to provide job seekers with comprehensive listings of positions in higher education and research institutions, with special emphasis on facilitating dual-career appointments and enhancing diversity. The website provides augmented information resources, networking, and outreach programs as well as information on the local area of interest to the job seeker and his or her partner.

The HERC website provides applicants with the ability to seek jobs by institution, job criteria, keyword, and/or geographic area. HERC sites are found around the country, including California, New England, and New Jersey. One of the long-range goals is to establish HERCs in other parts of the country.

For additional information, check out the website: www.mnyscherc.org.

Marsha Kipperman
Manager, Employment
Brookhaven National Laboratory

Letters can be submitted via letters@symmetrymagazine.org

Photo courtesy of Austin Ellsworth

Accelerator at the fair

Science fair season is here, so we at *symmetry* were not surprised when 12-year-old Austin Ellsworth of Spring, Texas, called with a few questions about his science fair project.

More surprising was the nature of the project: Austin had built a model of a linear accelerator, which seemed an unusual undertaking for a sixth grader.

"It's not a working model," he said, reassuringly. "To preserve the life of the whole city, I could not use working atoms. I had to fit this into a grocery bag, so it had to be small." What's more, the rules of the fair allowed him to spend no more than $25.

His accelerator is a piece of plastic pipe that contains a series of electrical contacts wired to 13 light bulbs. When Austin slides a metal wrench down a wide slit in the top of the pipe, as if swiping a credit card on a payment machine, the bulbs light up one after the other to represent the particle's journey. (The originally-planned rolling metal ball did not make good enough contacts.) The last light bulb is red, signifying that the particle has hit its target.

It may not fit the classic hypothesis-experiment-conclusion mold, but the project did get Austin thinking. He came to believe that someday, although maybe not in his lifetime, particle accelerators will become the equivalent of oil wells, generating antimatter that is shipped in futuristic containers to power plants and reunited with matter, releasing huge amounts of energy "so you can use the energy, like, to power your car, or whatever you want."

He was happy to learn that physicists at the Ecole Polytechnique in Palaiseau, France, had built a table-top particle accelerator, with potential uses in research and medicine.

"They say it's somewhat underpowered compared to conventional accelerators, but the fact that it exists is what matters—and that it works," Austin said. "I thought, 'Hallelujah, this is the evidence I need to show that particle accelerators are not too big! They're getting smaller.'" He speculates that Moore's law, which successfully predicted the trend toward smaller and more powerful computers, eventually will apply to accelerators, too, and who knows where that will lead?

Austin said he likes to read—"a lot on planes and baseball. Those are my two great loves." Science is another. As the Redd School Spring Science Festival approached, he was reading Stephen Hawking's *A Brief History of Time*, savoring the bits about black holes and antimatter even though "sometimes it kind of started reading like Portuguese to me."

He built his model with the help of his grandfather, who, Austin says, used to work for Lockheed and "is a fix-it-all, all-the-time man." The finished product, fastened to a wooden base and sprouting wires, came in on time and $10 under budget. He'll soon find out if it won a prize.

Glennda Chui

After extensive international collaboration and planning, the International Linear Collider has reached a milestone with its *Reference Design Report*. The reference design provides the first detailed technical snapshot of the next-generation machine.

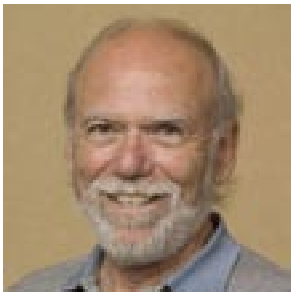


Photo: Reidar Hahn, Fermilab

The ILC's reference design

Almost two and a half years ago, the international physics community made a monumental decision on how to build the International Linear Collider. Just recently at the 2007 Beijing ILC Workshop in February, the ILC celebrated its second major milestone, the release of the *Reference Design Report*. I find it interesting that the first and second major milestones for this global project occurred in the very same room in the very same place in the world at the Institute for High Energy Physics in Beijing, China.

My last trip to China was actually ten years ago, and Beijing was a very different place then. A sea of bicycles has been replaced with cars, and the original hutongs are now surrounded by high-rise modern buildings. It is wonderful to witness such changes firsthand and see a nation progress much in the same way the effort to build a linear collider has progressed.

Photo: IHEP, Beijing

Photo: Barbara Warmbein

Photo: Barbara Warmbein

Photo: Elizabeth Clements

Within the last ten years, the ILC has evolved from an idea to a detailed design, produced by the Global Design Effort, a recognized international body that represents more than 1000 scientists and engineers who have dedicated their lives to making this dream come true. Every decision about the design for the machine has been made by this international body, something that I think is unique for science.

It has always been our plan to have every stage in the development of the machine conducted in an international manner. The recent publication of our *Reference Design Report* represents the true international cooperation that went into producing such a document that will guide us through the next engineering phase of the project.

The reference design provides the first detailed technical snapshot of the next-generation machine, defining in detail the technical parameters and components that make up each section of the accelerator. We succeeded in creating a design that can match the physics dreams and goals that have been outlined by the scientific community. As part of the reference design, we also produced a preliminary value estimate of the cost for the ILC in its present design and at the present level of engineering and industrialization. The estimate contains three elements:

- 1.8 billion ILC Units for site-dependent costs, such as the costs for tunneling in a specific region;
- 4.9 billion ILC Units for shared value of the high technology and conventional components; and
- 22 million person-hours = 13,000 person-years (assuming 1700 person-hours per person-year)

For this value estimate: 1 ILC Unit = 1 US Dollar (2007) = 0.83 Euro = 117 Yen

In arriving at an estimate, we used a value accounting process that has become standard for international scientific projects such as the ILC. Based on the detailed technical requirements of the machine, we determined the values of components based on a worldwide call for bids to obtain the required quality at the lowest reasonable cost. The estimate gives a first evaluation of the ILC at this time and will continue to evolve.

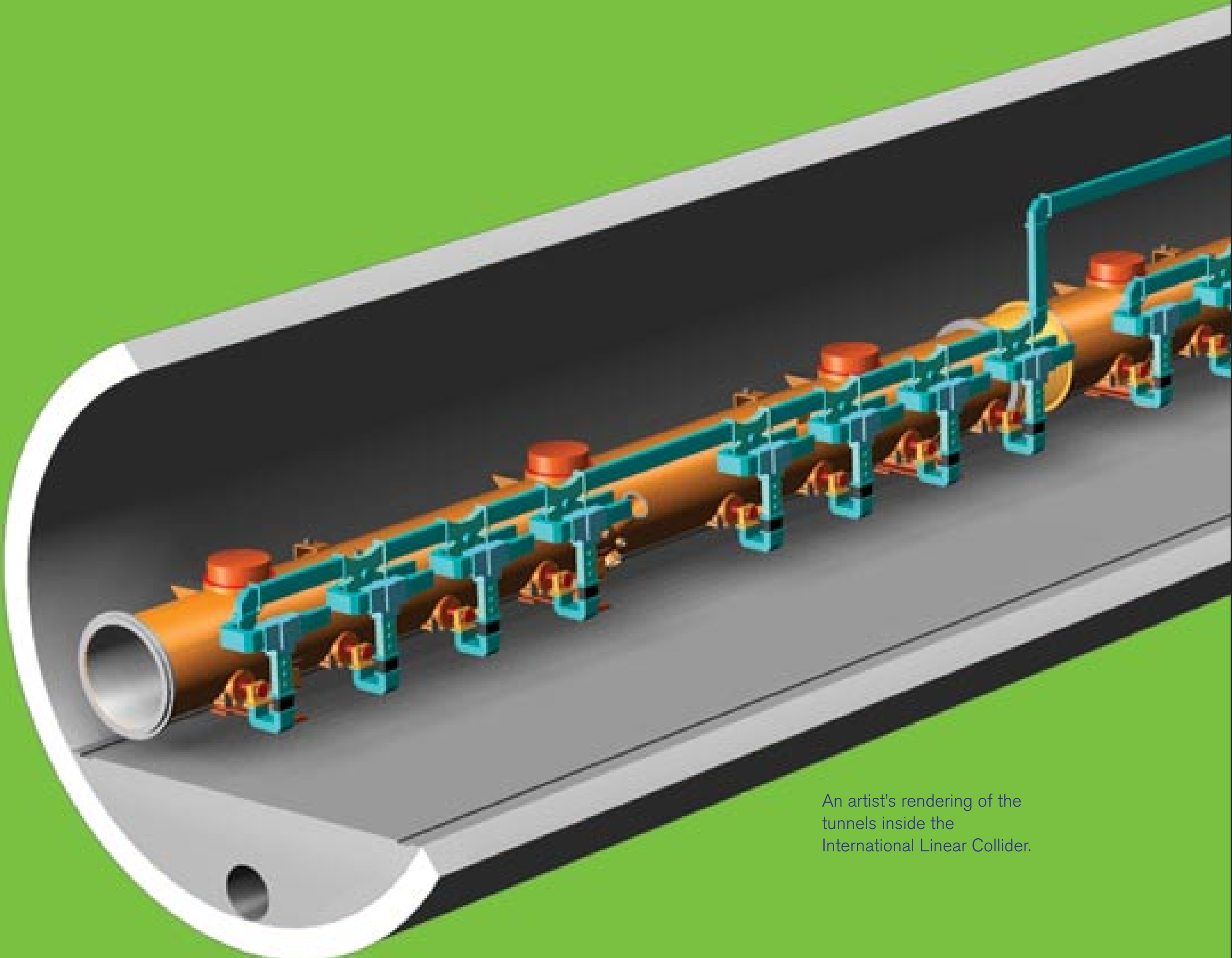
The value cost estimate will provide guidance for optimization of both the design and the R&D to be done during the engineering phase, which will start in the fall of 2007, after the final *Reference Design Report* will be completed. Based on what has been learned so far, we are confident that the value can be maintained at this level, as the design becomes more optimized during the next phase of the project.

Many very talented physicists and engineers did a tremendous amount of dedicated work in producing the reference design. This is just one step along the way, and we hope to come back soon with our next accomplishment, maybe even in the same room in Beijing.

Barry Barish is the director of the International Linear Collider Global Design Effort.

Below: Members of the ILC communication team celebrating the release of the *Reference Design Report*. Pictured: Perrine Royole-Degieux, IN2P3 (France); Neil Calder, SLAC; Barbara Warmbein, DESY (Germany); Youhei Morita, KEK (Japan); Elizabeth Clements, Fermilab (USA)

Photo: Maxine Hronek



An artist's rendering of the tunnels inside the International Linear Collider.

Toward an International Linear Collider

By Elizabeth Clements, ILC Global Design Effort

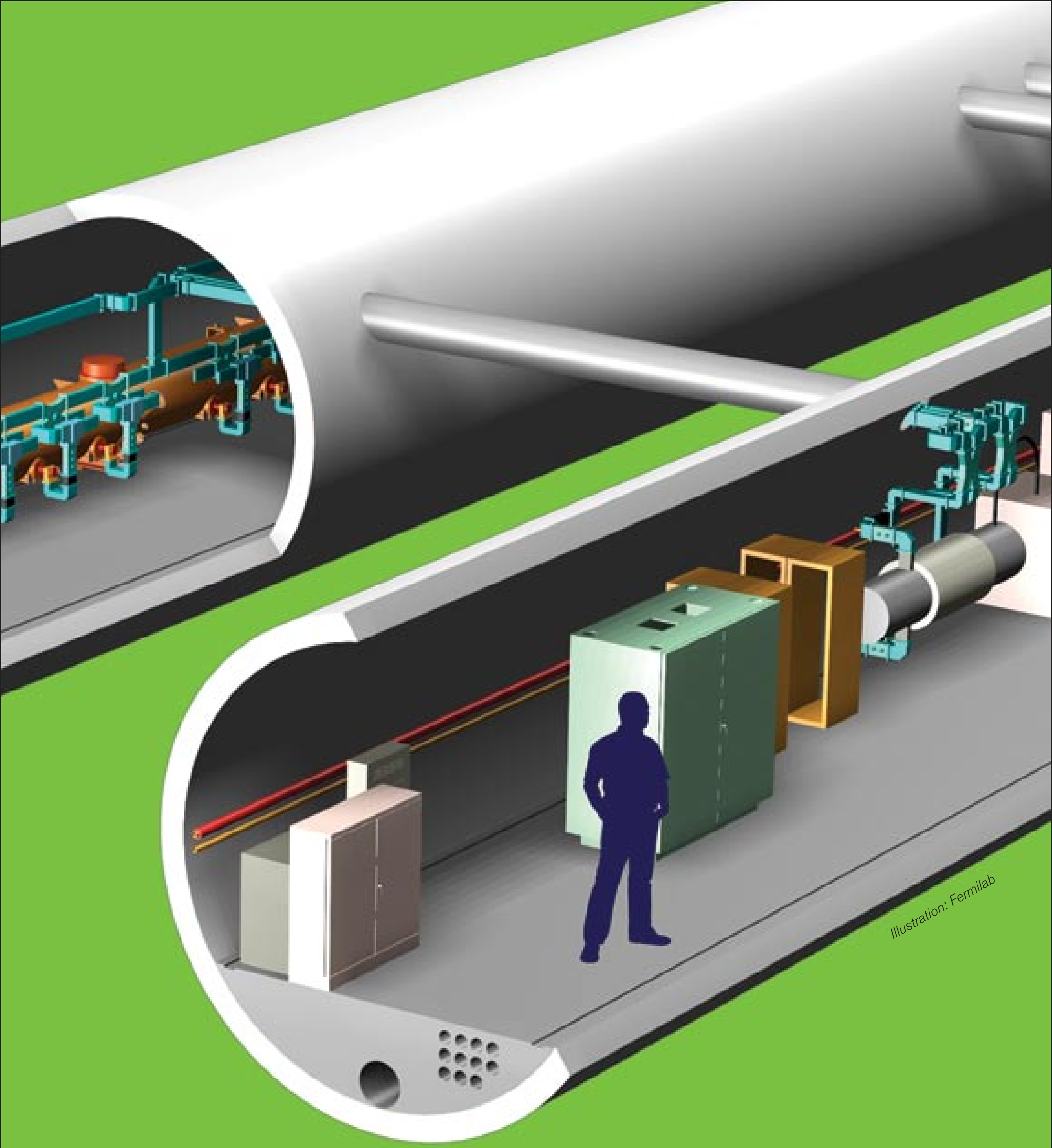


Illustration: Fermilab

The ILC reached a major milestone when it presented the first detailed technical snapshot of the machine in Beijing. The announcement marks the beginning of the engineering phase of the project.

Photos courtesy of IHEP, Beijing

Attendees at the ICFA meeting in Beijing.

Higgs Boson. Dark Matter. Dark Energy. Extra Dimensions. These are all buzz words that will make the heart of any particle physics enthusiast flutter. The International Linear Collider, a proposed next-generation accelerator, recently took one step closer to discovering exactly what makes these words buzz.

On February 8, 2007, at a press conference held at the Institute of High Energy Physics in Beijing, China, the International Committee for Future Accelerators (ICFA) announced the release of the *Reference Design Report* for the ILC.

"This is a major next step in the development of the ILC," said Albrecht Wagner, ICFA chair and director-general of the German laboratory DESY. "In recent years, many steps have been taken toward building an ILC. The work on the ILC has been scrutinized and reviewed by many international bodies and has received strong encouragement and support for moving forward with this project."

Gateway to the Quantum Universe

In the last 10 years, scientific observations have revealed a universe far stranger and more wonderful than people had ever imagined: a universe filled with dark matter and dark energy, where ordinary matter is only a tiny minority. The next generation of particle accelerators will stretch our imagination even further. It might reveal new forms of matter, new forces of nature, and new dimensions of space and time.

Reaching these ambitious goals will be a major challenge. New accelerator-based experiments are pushing the boundaries of technology in particle acceleration, materials engineering, detector development, and computing.

The proposed International Linear Collider, a 20-mile-long particle collider, is at the forefront of these endeavors. Together with the Large Hadron Collider, scheduled to start operating at the European laboratory CERN in 2007, the ILC would answer some of science's greatest questions about the nature of the universe. With its high-energy electron-positron collisions, the ILC would give scientists the information they need to understand nature's mechanism to create mass, explore the intriguing properties of supersymmetry, probe dark matter candidates, and possibly discover new forces that may show the way to a unified theory.

The reference design

The reference design defines the technical parameters and components that make up the accelerator. The RDR is the first technically-detailed snapshot of the proposed electron-positron collider. This report will guide the development of

the worldwide R&D program, motivate international industrial studies, and serve as the basis for the final engineering design needed to make an official project proposal later this decade.

"A talented group of dedicated scientists and engineers from particle physics laboratories and universities around the world has been working together for more than a decade toward an ILC," said Barry Barish, director of the Global Design Effort for the ILC. "In the 1990s, several of our laboratories developed the key technologies, and that has been followed by an extraordinarily productive period. ICFA made a decision to base the design on superconducting rf technology; a GDE was initiated to produce a design for the accelerator, and the first stages of the design and costing have now been completed."

As part of producing the RDR, the GDE estimated the value of components and labor needed to complete the ILC. The estimate came out to roughly 7 billion ILC Value Units, a number that can be converted into costs in local currencies taking into consideration differences in local accounting systems. The values of components were determined by a worldwide call for bids specifying a required quality and assessing a lowest reasonable cost. (See more information on the value estimate on page 8.)

Once the *Reference Design Report* is internationally reviewed, the engineering phase begins. The value cost estimate will provide guidance for those optimizing the design and doing the R&D in that phase. GDE members speaking about the value estimate are confident that the value will not increase substantially as the design is optimized during the next phase of planning.

"On the behalf of the International Linear Collider Steering Committee, we appreciate the enormous effort led by the Global Design Effort," said Shin-ichi Kurokawa, Chair of the ILCSC, an international body that promotes the construction of an electron-positron linear collider through worldwide collaboration. "We especially appreciate the last half year's heroic effort of the GDE to make the RDR and their cost consciousness in modifying the design without compromising the physics. We have to work hard to accomplish this project, but we have a great milestone to move forward."

Breaking new ground

While publishing a reference design is important for focusing the next steps of the project, the most significant achievement could be hundreds of scientists and engineers from around the world coming together to produce a 700-page document. After the release of the report, academic and scientific leaders recognized the significance of this milestone.

"The GDE has produced some extraordinary reports," said Princeton University president-

Photo: Reidar Hahn, Fermilab

Scientists and engineers from around the world are collaborating on R&D for the International Linear Collider.

emeritus Harold Shapiro, who chaired the National Academy of Sciences' EPP2010 Report committee. "These are inspiring documents, and they are almost unique in the field of science because they represent an international collaboration. This by itself is an enormous accomplishment."

Many universities and DOE national laboratories across the United States contributed to the worldwide effort. SLAC director Jonathan Dorfan and Fermilab director Pier Oddone both applauded this hard work and celebrated the achievement in global collaboration.

"The RDR is the product of a new process in planning future particle physics installations, as it was not written by staff from one laboratory but by engineers and physicists from all over the world," said Dorfan. "The new techniques and protocols of global collaboration that have been established for the on-time publication of the RDR have broken completely new ground."

Oddone echoed these comments. "Hard decisions were made within the particle physics community to write the *Reference Design Report*," he said. "The fact that people came together across three regions is truly remarkable and bodes well for the future."

Photo: Reidar Hahn, Fermilab

A prototype of a component for the ILC.

Photo: KEK

Magnets will keep particles on course as they zoom through the machine.

The "I" in ILC

Physicists have a long and very successful experience with the construction of accelerators and detectors as international projects. Recently, for example, the construction of the major detectors for the LHC has required global collaborations of physicists with significant hardware coming from Europe, Asia, and the Americas. As well as technical success in carrying out big projects, this mode of working promotes international understanding. For young people especially, the opportunity to work closely with peers from other cultures is a valuable and often eye-opening experience that breaks down cultural barriers and stereotypes.

In the case of the ILC, scientists and engineers will need to take this successful record of collaboration to the next level: build and operate a global facility for high-energy physics.

The GDE, and the process that led to it, has shown that it is possible for scientists from around the world to come together in pursuit of a common goal. "We can take tough decisions such as the choice of rf technology and can focus and align our R&D efforts," Barish said. "We can exercise effective project management, despite our geographic spread and separate national funding sources."

As the project moves towards approval and construction, the GDE intends to add greater formality to the management structure. As part of this evolution, for example, the GDE will incorporate a project management team into the next phase of the project. This new project manager and support team will not be centrally located but instead will follow the precedent established by the GDE and also operate virtually.

"Many aspects of the GDE work well, and therefore we should evolve our structures for the engineering design rather than have a complete revolution," said Brian Foster, ILC Regional Director for Europe. "However, we certainly need a different skill set that is grounded much more in engineering."

The GDE hopes to have a project manager in place by this summer, who will then organize the engineering effort into work packages. "We want to add project management to produce the deliverables without throwing away a lot of the things that are working well," Foster said.

Next: Global R&D

With the release of the reference design checked off the GDE's master to-do list, the organization turns its attention to the worldwide ILC R&D program that involves the three regions: Americas, Asia, and Europe.

"The RDR will point the way for a focused worldwide R&D program on key technologies," said Gerry Dugan, ILC Regional Director for the Americas. "In the Americas, we look forward to fully supporting the evolving machine design, contributing to the key R&D goals, and developing our regional capabilities for participation in the global ILC project."

Defining a global R&D program that focuses on the most crucial technical aspects for successfully completing an engineering design by the end of this decade is now the highest priority for the GDE. "We need to maintain the momentum of the project," said Brian Foster, ILC Regional Director for Europe. "We have to produce an engineering design that we believe we can build and sell to our governments in sufficient details by 2010 to allow approval for construction. We need to give them a document that allows them to say yes."

From designing to funding to eventually building, the ILC is a global endeavor, and the release of the RDR reflects the successful international cooperation of the project.

"Accomplishing the reference design is a crucial step forward for a very challenging international scientific endeavor," said Mitsuaki Nozaki, ILC Regional Director for Asia. "The strong international partnership has been unprecedented. We hope to keep up the international momentum in the next phase, when a coherent R&D plan will turn the reference design into a real engineering design for this global project."

Photo: ILC

The International Linear Collider will use 16,000 superconducting cavities to accelerate electrons and positrons to 99.9999999998 percent of the speed of light.

Detectors will capture the array of new particles that emerge from each collision.

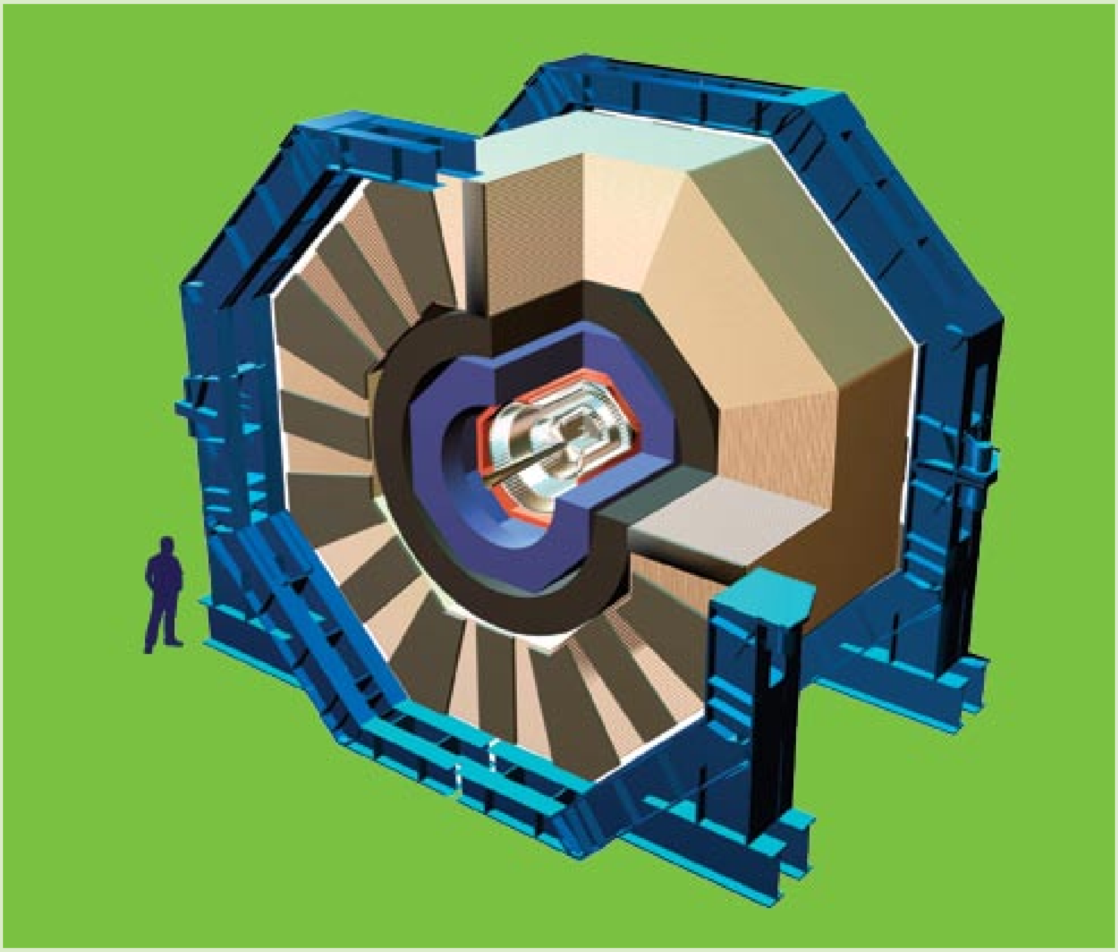
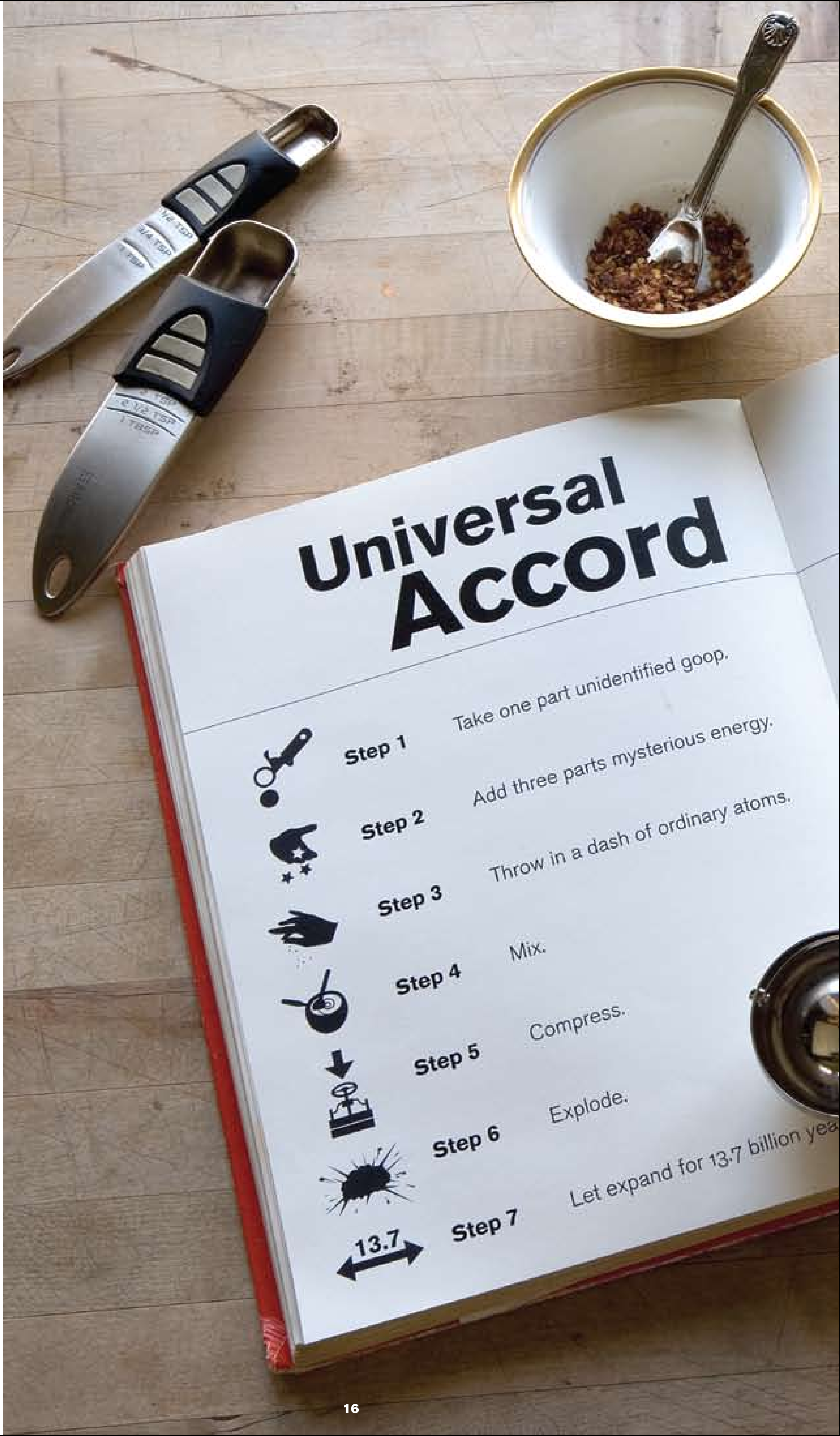
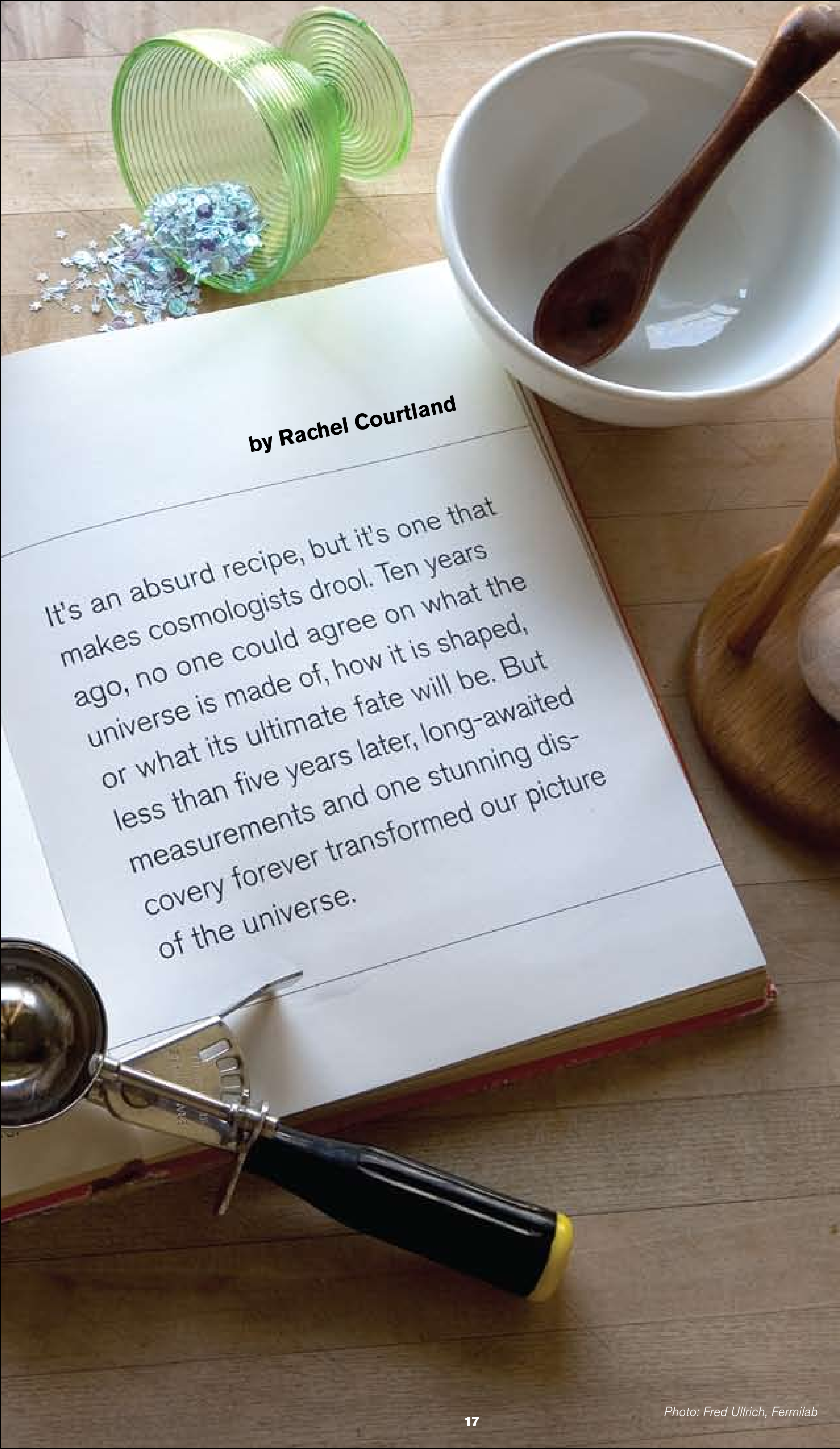


Illustration: SLAC


Universal Accord
Step 1 Take one part unidentified goop.
Step 2 Add three parts mysterious energy.
Step 3 Throw in a dash of ordinary atoms.
Step 4 Mix.
Step 5 Compress.
Step 6 Explode.
Step 7 Let expand for 13.7 billion yea
13.7
1/2 TSP
1/2 TBSP
1 TBSP



by Rachel Courtland

It's an absurd recipe, but it's one that makes cosmologists drool. Ten years ago, no one could agree on what the universe is made of, how it is shaped, or what its ultimate fate will be. But less than five years later, long-awaited measurements and one stunning discovery forever transformed our picture of the universe.

Photo: Fred Ullrich, Fermilab

1. Take one part unidentified goop.

The resulting model, often called the concordance model, holds that 22 percent of the universe is composed of dark matter, which pulls the universe together through gravity, and 74 percent dark energy, which pushes the universe apart. It is a cosmic recipe that unifies all astronomical observations to date, and though researchers do not yet understand what the ingredients are really made of, they know it tastes right.

"The concordance model is a real aesthetic achievement," says Steven Kahn, an astronomer at the Kavli Institute for Particle Astrophysics and Cosmology at Stanford Linear Accelerator Center and Stanford University. "We have a really successful theory. It's just amazing how well it works. That story hasn't been told." Part of the problem, he says, is that scientists don't dwell on their successes. They're always looking at the next big mystery.

In the mid-1990s, there were many mysteries in cosmology; the field had reached a crisis. Armed with mounting data on how galaxies clump together, astronomers plied the halls of their departments insisting that our universe is unexpectedly light, a bantamweight in the realm of possibilities.

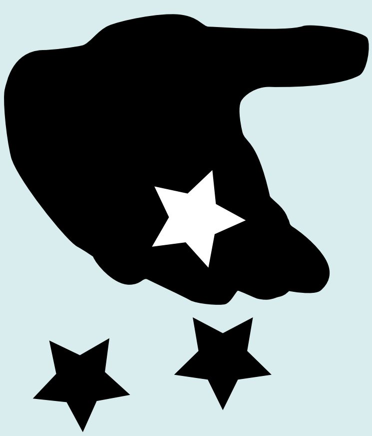
"There were many discussions, many talks, many meetings at that very early time," says Neta Bahcall, an astronomer at Princeton University, who worked on the mass measurements and was an advocate of the idea that the universe is light. Many cosmologists were reluctant to believe Bahcall and her colleagues.

The resistance to the idea of a low mass universe ran deep. The reigning picture of the big bang, the inflation model, called for a flat universe, with critical density of one: just enough energy and matter to keep it expanding forever without falling back in on itself. No one was delighted with the idea of abandoning inflation: it was the simplest explanation for how the universe became a stew instead of a purée, studded with stars and galaxies.

Theory strongly favored the idea of a flat, "just right" universe. But observational evidence weighed against it. Measurements of the universe's large scale structure—the distribution of galaxies stretching back in time—suggested that the total amount of ordinary atoms and cold dark matter was only a third of what was required.

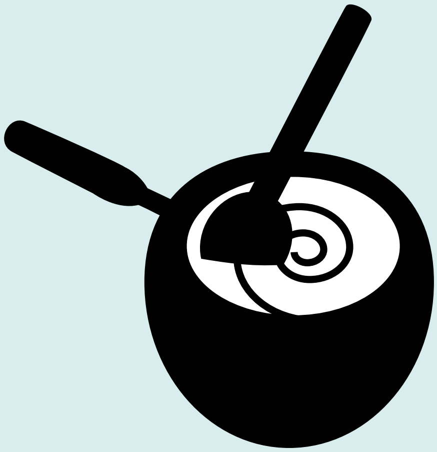
Even as the mass density closed in on its current value of 26 percent, some theorists continued to entertain the idea that there was a fundamental problem with the observations. "Theorists kept saying maybe the observers were not seeing the mass density because they were not looking far enough," says astronomer Adam Riess of Johns Hopkins University. "It was always between galaxies or beyond, or just a little farther out."

Others proposed wild ideas to account for the unexpected measurements. Perhaps there was some form of "hot" dark matter, moving at relativistic speeds, that could account for the missing 70 percent. Perhaps the universe is not spatially flat after all, and instead shaped like a four-dimensional saddle. Or perhaps it was time to



2. Add three parts mysterious energy.

3. Throw in a dash of ordinary atoms.



4. Mix.

resuscitate the idea of a cosmological constant, some mysterious energy in empty space with negative pressure, something that pushes out when pressed in.

In the end, the problem was solved by accident. In the early 1990s, two rival groups of astronomers began work on a different way to weigh the universe by using supernovae, stellar explosions that dot the distant, ancient sky. Both teams expected to confirm the results of the galaxy cluster measurements, showing a low-mass universe. They also expected to see evidence of a universe that is still expanding but slowing down. "We were expecting to find a small amount of deceleration," says University of California, Berkeley, astronomer Alex Filippenko, who worked on the High-*Z* Supernova SearchTeam.

The supernova technique was still in its infancy when in late 1997, email bearing strange, new data zipped back and forth across a dozen time zones. The results were confounding. Supernova explosions in distant space were 25 percent dimmer than expected.

The researchers thought at first it might be dust or some minor glitch in a program. But as crosschecks were run and possible mistakes eliminated, both teams were left with one conclusion: the expansion of the universe is not slowing down—it is accelerating.

The implications were not immediately clear. "I've been describing it to people as the slowest eureka moment you'll ever hear of," says astronomer Saul Perlmutter, who led the Supernova Cosmology Project from Lawrence Berkeley National Laboratory.

The gravitational attraction between the matter in the universe was putting on the brakes, but something else, pushing against it, seemed to be hitting the accelerator.

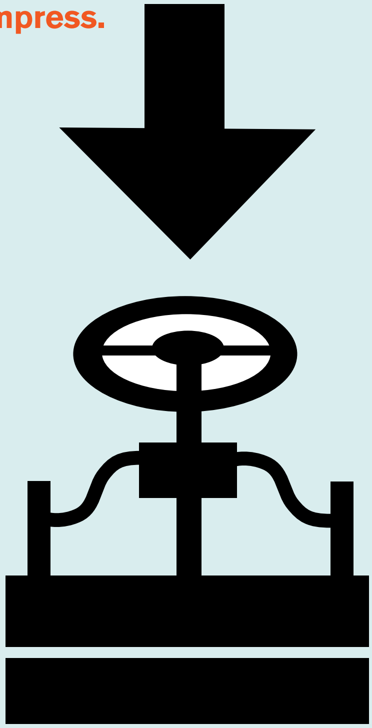
"I expected the community to massacre us," says astronomer Brian Schmidt, who led the High-*Z* team from the Mount Stromlo and Siding Spring Observatories in southeastern Australia. "It was a crazy result, and I expected they would tell us we were crazy."

Part of Schmidt's hesitation was that the simplest way to explain the findings was the cosmological constant. Einstein originally introduced the fudge factor to counteract the attractive force of gravity and make a static model of the universe, later retracting it when Edwin Hubble released his measurements of an expanding universe in 1929. He is said to have called the invention of a nonzero cosmological constant, or lambda, his greatest blunder.

"Lambda is kind of the last resort of scoundrels. It's always been lurking in cosmology," says theorist Michael Turner of the University of Chicago.

"It's ugly," says cosmologist James Peebles of Princeton University. "If you or I were making a universe, we wouldn't put it in."

5. Compress.



Still the data seemed to call for it. On January 12, 1998, on the eve of his honeymoon, High-*Z* team member Adam Riess was still in feverish discussion over the supernova results, and what it would mean to have found a non-zero cosmological constant. "In your heart you know this is wrong, though your head tells you that you don't care and you're just reporting the observations," Riess' teammate Robert Kirschner wrote. Riess replied within the day. "The results are very surprising, shocking even," he wrote. "The data require a nonzero cosmological constant! Approach these results not with your heart or head but with your eyes."

Despite their fears, the idea of an accelerating universe was welcomed, and in record time. "It didn't take long," says Bahcall. "It was much quicker than it took people to believe in the existence of dark matter, which took decades." Theorist Sean Carroll of the California Institute of Technology agrees, "Everyone was ready to believe something dramatic about the universe." It was just the evidence cosmologists had been waiting for.

Some cosmologists were quick to accept the new results. "I like to call the discovery of cosmic speed-up the most anticipated surprise," says Turner, often credited with coining the term 'dark energy.' "What a result. People believed it instantly and why? Because it was the missing puzzle piece. It made everything fit together." With dark energy, the low mass universe became consistent with inflation.

Others were more hesitant to embrace acceleration, waiting for confirmation from other sources. They didn't have long to wait. Within several years, even more solid measurements of supernovae and large-scale structure supported earlier observations of cosmic acceleration. Ground- and balloon-based studies of the universe's oldest radiation, the cosmic microwave background, began to show hints that the universe might be flat. In 2003, the first data from the space-based Wilkinson Microwave Anisotropy Probe arrived and ushered in the era of precision cosmology. The WMAP results swept away all doubt, independently confirming the existence of dark energy and conclusively demonstrating that the universe is very close to flat.

After WMAP, many potential cosmological theories were ruled out and the evidence pointed strongly toward the lambda-CDM model—a flat universe with a non-zero cosmological constant and a serving of cold dark matter. Often called

6. Explode.

7. Let expand for 13.7 billion years.

the concordance model for its unassailable collection of interlocking measurements, the lambda-CDM model has unified not only the picture of the universe, but also the contentious and divided community of researchers who study it.

"The status quo in cosmology is that everybody would disagree," says Riess. Now that has changed.

"Every attempt to understand the universe on large scales now begins with this as the model," says Carroll. "Whether or not you try to argue for some alternative, this is the place you start."

But the model does have limitations. If there is a cosmological constant, quantum mechanics suggests it should be as much as 120 orders of magnitude greater than what has been observed.

What's more, there is no reason to assume that dark energy, whatever it may be, is given by the cosmological constant. No one knows whether the concentration of dark energy in the universe is the same as what it was at the time of the big bang, or whether it is the same from place to place.

Nevertheless, the observational evidence for the model has only gotten stronger in the years since the supernova measurements were released. "There's so much data that supports this theory, lambda-CDM, that it's become the standard model of cosmology," says Joel Primack, a theoretical physicist at the University of California, Santa Cruz. Primack is trying to turn the community on to his term for the dark energy-dark matter model. He thinks it should be called the double-dark model. "It makes you think of coffee or ice cream," he says. So far he has few takers.

Concordance has also resolved a number of other problems that plagued cosmology in the mid-1990s, the most contentious being the age of the universe. Astronomers were making increasingly more precise measurements of the current expansion rate of the universe, but when they tried to use the value to calculate the age of the universe, they found a problem. Globular clusters, which orbit around galaxies including the Milky Way and contain the universe's most ancient stars, appeared to be older than the universe itself. Some stars appeared to be over 12 billion years old. The new model resolves this problem, pinning the age of the universe at 13.7 billion years.

"It's this wealth of crosschecks that really warms the cockles of one's heart," says Peebles. Even a few years ago, Peebles says, he was far more skeptical of the model.

With lambda-CDM as a starting point, astrophysicists are now poised to go after an even deeper mystery, namely understanding whether dark energy comes from a cosmological constant or is made of something even stranger. Proposals for ground-based projects like the Large Scale Synoptic Telescope and the Dark Energy Survey are under consideration. Space-based missions to probe the nature of dark energy are also being considered, including the Joint Dark Energy Mission, an element of NASA's Beyond Einstein program.

What comes next is anyone's guess. "It's a real puzzle," says Peebles, "and a real opportunity for the next generation."

Working Outside the Accelerator

By Jennifer Yauck

A PhD in particle physics can be a stepping stone to a career outside physics research.

It's a weekday morning and a man's voice comes over the radio: "Here's the thing about life in a cave: You don't often get the chance to mate with things in other caves. So these little creatures—after generation and generation, thousands of years—evolve, and sometimes become their own species, unique in the world."

The voice belongs to David Kestenbaum, science correspondent for National Public Radio, who on this day is talking about biologists searching for undiscovered organisms in the caves of Tennessee. Tune in another day, however, and he might be reporting on the shelf life of plutonium in nuclear weapons, the engineering of levees in New Orleans, or the latest launch of a space shuttle. Although he is a journalist by profession, science is a natural beat for Kestenbaum: he holds a PhD in particle physics.

Particle physics research, in fact, may have once seemed the career that Kestenbaum—who worked at Fermilab while still in high school—was most certainly headed towards. But after completing his doctorate, he stepped off the research path. "I had been doing physics for so long, and I felt like I hadn't really looked around," he says. "So I took a walk from it and came

David Kestenbaum, whose Harvard doctoral thesis focused on the discovery of the top quark, crawls through a cave while covering a story for National Public Radio.

Photos: Jessica Goldstein, NPR

“It’s important for people in Washington to have a general understanding of the scientific process.”

across something interesting.” That “something” was journalism, and it has been his career ever since.

Like Kestenbaum, other particle-physics practitioners have also ventured from the research path to explore other career options. The stages at which they leave vary, as do their reasons for pursuing alternate professions. Some continue to apply their physics skills and knowledge, be it directly or indirectly, in their new careers; others are removed enough to simply view the field from afar, as enthusiasts. But most, if not all, find that their rendezvous with particle physics—no matter how long or short—has been valuable.

Taking a different path

When young students of physics look to the future, chances are they envision a career in research. And perhaps it’s no wonder: The notion that a physics education ultimately leads to a research destination is deeply ingrained in the field’s culture. For many, it’s also something of an automatic assumption, maybe even an unconscious expectation, that those who enter the discipline will not only aim for that destination, but will get there by a series of clearly defined steps: bachelor’s degree, doctoral degree, postdoctoral fellowship, assistant professorship, associate professorship, full professorship.

Although research is a noble pursuit, the reality is that it isn’t the only career that people with a background in particle physics choose to pursue. Furthermore, it is but one option of many that new recruits to the field need consider.

People choose careers outside traditional particle physics for a variety of reasons and at various points in their professional development. For some, including Kestenbaum, it’s a matter of discovering what they are good at or where their passions lie. When Gregory Jaczko was finishing his doctorate in theoretical particle physics, he began noticing that his penchant for science policy work was taking up a lot of his time. “I started to think I should pay attention to my hobby,” he says. And so he did. After graduating, he tried his hand as a congressional science fellow for US Representative Edward Markey. The work was a good fit for him, and soon his hobby became his profession. After his fellowship, he went on to serve as science policy advisor and appropriations director for US Senator Harry Reid. Today, Jaczko is one of five commissioners heading the US Nuclear Regulatory Commission, the federal agency responsible for overseeing matters related to nuclear energy and safety.

Both Kestenbaum and Jaczko still find science entwined in their current professions, but that’s not necessarily the case for everyone who follows their passion to a different career. Growing up in England, John Butcher had interests in both music and physics. But at the school he attended, “you did either arts or sciences,” he says, so he chose the sciences, a path he eventually followed all the way to a doctorate in theoretical particle physics. Over the course of the years he spent studying science, Butcher remained involved in music and was developing into a serious saxophonist. By the time he finished his PhD, he realized he couldn’t do both physics and music to the standards he hoped to achieve, and, he says, “I felt I had to go with one or the other.” This time, he chose music. “Music is a much more social activity, and I felt that was a healthier option for me,” he says. Now a professional saxophonist (who “would like to live long enough to know if the Higgs exists”), Butcher has recorded over 50 albums and toured in North America, Europe, and Japan.

Sometimes the decision to pursue a career outside of research is less about passion, as it was for Butcher, and more about practicality, as turned out to be the case for Robin Stuart.

Gregory Jaczko, one of five commissioners on the US Nuclear Regulatory Commission, completed a doctorate in theoretical particle physics at the University of Wisconsin-Madison before pursuing a career in policy.

Photo: Todd Schvaneveldt

Saxophonist John Butcher, who holds a doctorate in theoretical particle physics from Imperial College in London, performs at the Vancouver Jazz Festival.

Photo: Brad Winter

"I can really appreciate that there is a very human side to particle physics that most people outside of particle physics simply don't see."

After nearly two decades of work in theoretical particle physics, the former assistant professor now has a second career as a quantitative analyst, or "quant," for the financial institution Merrill Lynch. Stuart was attracted to finance after his area of work, high-precision physics, began to wind down at his institution, the University of Michigan, Ann Arbor. "It was the right moment to step out," he says. And, he notes, it's not a bad thing to be a spectator. "I have weekends off now," he jokes.

Physics applied

No matter the reason behind it, the decision to leave particle physics after dedicating effort, time, and money to the pursuit may stir up a disconcerting question: Was it all for naught? Not necessarily. Many particle physics practitioners find that their training serves them exceedingly well in their chosen careers. Skills that physicists can easily take for granted, such as the practice of critical thinking, are often prized in other professions.

Jaczko says that his physics background taught him how to "tackle and analyze problems" as a policy maker. What's more, Jaczko points out, a need exists in government and policy for people with a background in physics or other sciences. "Some of the most important issues rest on scientific or technical questions," he says. "It's important for people in Washington to have those kinds of skills, and to have a general understanding of the scientific process."

Training in particle physics provides more than just analytical skills, however. "The quantitative training from physics is second to none," says Stuart. As a quant at Merrill Lynch, Stuart draws heavily on his own math skills, building models to analyze the financial risks of the firm. Physicists make natural quants, he says, because they "speak the language" necessary for developing the kinds of complex models that are used in finance. The finance world, in fact, has attracted many physicists over the years.

In still other disciplines, knowledge of particle physics is itself a more valuable asset than analytical or quantitative skills. After completing postdoctoral work in experimental particle physics, Valerie Jamieson eventually went on to become *New Scientist's* physics features editor, a role that requires her to stay atop the latest developments in the field and determine content for the magazine. Her knowledge comes in handy on the job, giving her perspective on the science she encounters as she talks with physicists, attends conferences, and reads scientific journals. "It helps me spot interesting papers that have obscure titles and don't scream out 'important discovery,'" she says. In addition, she knows firsthand the "ingenuity, blood, sweat, and tears" that go into building a particle detector. "I can really appreciate that there is a very human side to particle physics that most people outside of particle physics simply don't see," she says. "I can bring that to a much wider audience."

Reflections on leaving

When you ask people who left particle physics research why they entered the field in the first place, their answers are often filled with enthusiasm and peppered with words like "mind-blowing" and "fascinating." Many speak of the thrill of explaining the supposedly inexplicable, of unlocking the secrets of the universe and how it ticks. "It wasn't walking on the moon," says Kestenbaum of his time at Fermilab, "but it felt close."

And so it may not be surprising that a healthy dose of soul searching sometimes precedes the decision to leave the field for a different career. "It was a leap," says Jamieson, who thought long and hard before making her decision to pursue journalism. "I felt if I left research, I wouldn't be able to get back into it." Nor is it necessarily surprising that those who make the leap sometimes feel pangs of nostalgia. Jaczko, for instance, says at times he misses the work and daily learning of his graduate school days, and Kestenbaum admits he is "sometimes envious" when he interviews a scientist after a great discovery.

Yet, in spite of the fascination with particle physics and the moments of soul searching and nostalgia, many people who leave research seemingly have little regret about the move, and in fact speak of their new careers as enthusiastically as they speak of particle physics. "I can't think of any other place I'd want to be," says Kestenbaum.

At the same time, they appreciate the role physics played in getting them to where they are now, and they value the skills and knowledge they developed during their training. Many even say they would still go the same route if given the chance to do it all again. For them, particle physics may not have been the final destination, but unquestionably it has been a vital part of the journey.

A former theoretical physicist at the University of Michigan-Ann Arbor, Robin Stuart now builds financial models as a head quantitative analyst for Merrill Lynch.

Photo: Merrill Lynch

Valerie Jamieson completed a postdoctoral fellowship in experimental particle physics at Oxford, and then went on to become physics features editor at *New Scientist* magazine.

Photo: Anita Staff

day in the life: traveling detector

For million-dollar components that travel thousands of miles to become part of a particle detector, the most perilous part of the trip might be airport security.

By the time 2007 started, we had carefully plotted the best way to get 10 delicate pieces of equipment to Geneva, where they will sit at the heart of a 12,500-ton detector in the new Large Hadron Collider at CERN, the European particle physics facility.

We decided the do-it-yourself solution was cheapest and safest: We would carry them by hand on a commercial flight, two at a time, and put each one in its own passenger seat. But flying coach also poses risks, from jostling and bumping to condensation caused by abrupt temperature changes. The same kind of electrostatic discharge you get from rubbing your feet on the carpet and touching a door knob is enough to wipe out an instrument, and the belt that takes carry-ons through the X-ray machines is notorious for generating those charges. Then there are the rollers' bump, bump, bump. We didn't want that.

Clearly the security personnel needed to be able to inspect the devices without actually touching them. So we built a special acrylic box with an internal aluminum mount. This box nestled into a foam-lined, hard-shell case that could fit on an airline seat. Lalith Perera, a postdoc at the University of Iowa, would accompany me on this first run.

The devices in question, called Forward Pixel Half Disks, are the smallest and innermost of the detector elements in one of the LHC's two giant detectors, the CMS Tracker. They'll be the first ones hit by particles coming out of collisions. They're quite light, less than a kilogram each, and covered with featherweight wafers of silicon.

The half-disks are designed to survive the intense radiation environment inside an operating collider. They are sturdy enough to survive a plane trip, but not to survive poking by your fingers. They have these extremely delicate, fine wires. As

Wilson Hall and sculpture
at Fermilab

A half-disk in its transport case

Bert Gonzalez and the two half-disks

John Conway and Lalith Perera leaving SiDet

Lalith and the half-disks in the Swiss International Air Lines lounge for the silicon wafers, imagine the thinnest glass you've ever encountered. I would say they're about as robust as a potato chip. On the other hand, we've glued them to thin plates of beryllium, which are very light but mechanically strong, so they are unlikely to flex much.

The two disks we would deliver in January were prototypes for the collider's initial engineering run this fall. But the next eight would be the real things, and much more expensive. It's hard to put a price tag on these things, because they represent the labor of 100 people for 10 years. If they were lost or destroyed, we'd have to do everything again.

The original plan was to fly from Fermilab, where the devices were built, to Zurich; there we would go through customs and drive to Geneva. But the day before leaving, we discovered that in order to avoid paying import duty on the devices we would have to go through customs in Geneva, which has a special arrangement with CERN. So we would have to fly from Zurich to Geneva and risk getting hung up while changing planes.

After checking in at Chicago's O'Hare Airport we called our Transportation Security Administration contact, Daryl Wilson. His supervisor guarded our cases while we took the rest of our bags through the normal process. Once on the secure side, we opened the cases and removed the acrylic boxes for inspection; meanwhile, the cases went through the X-ray machine. The security screeners swabbed for explosive residues and peppered us with questions: What the heck were these things? What was the experiment at CERN for? It clearly was a bit of excitement for them in an otherwise routine day.

Once on board, we tried to set the cases on the seats, but the flight attendant insisted that they had to go on the floor. So that is what we did, with some pillows for additional cushioning. The flight was uneventful, and Lalith and I managed to eat and sleep.

In fact, the only problem we encountered was at the Zurich airport. We showed up cold at security and had to explain the whole thing from the bottom up. At first they were adamant: We had to put the devices through the X-ray machine. We smiled politely and asked to see the supervisor, who was nice and cordial and also said no. We took one of the detectors out

The half-disks safely aboard, cushioned by pillows

3

Zurich Airport

4

The Tracker Integration Facility and Building 28 at CERN of its acrylic case and showed him just how delicate it was. At that point he relented.

In Geneva we were met at customs by a CERN person who, thanks to advance work by our postdoc, Ricardo Vasquez, had exactly the right papers to zip us straight through. We got our rental car and got ourselves to CERN.

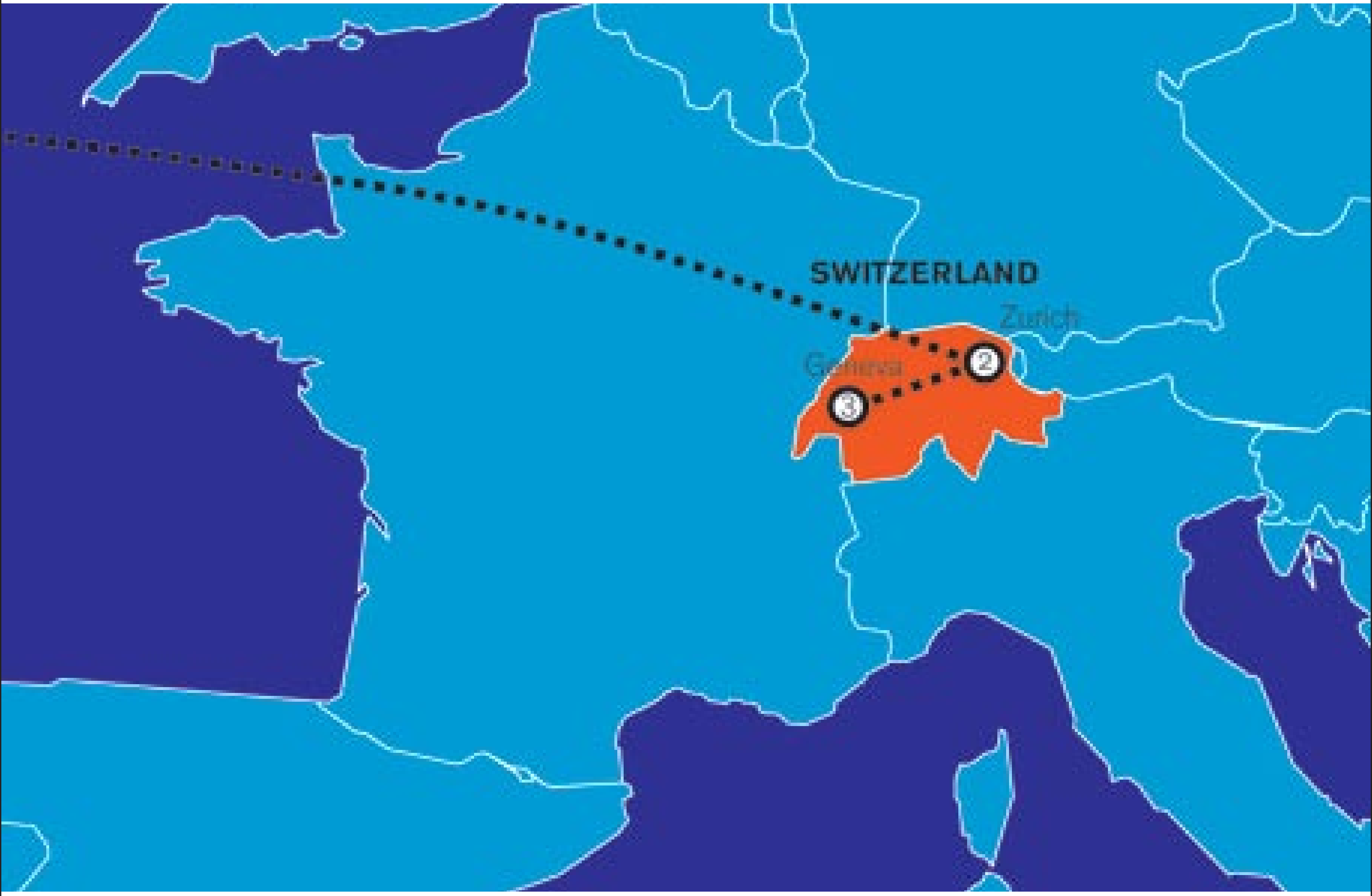
Like most labs at CERN, the CMS Tracker Integration Facility is housed in a nondescript industrial building. A team of postdocs has been working since December in our assigned clean room, bringing up the electronics systems needed to test the detectors after they are reassembled.

We just learned in the last week or so that the devices are working, so that's a huge relief. The guys at the integration facility have done a great job and are eager for more.

We've spent a lot of time lately thinking about how to get the half-disks into the detector. It's not like we can plunk them in. It's a ship-in-a-bottle problem. The half-disks go in on rails. You have to synchronize the two halves and mesh them together once they're in. We have a lot of work to do on this.

Four more shipments to go!

Story by John Conway as told to Glennda Chui



In late 2006, a component of the Karlsruhe Tritium Neutrino Experiment (KATRIN) traveled from Deggendorf, Germany, to a laboratory in Karlsruhe, only 400 kilometers away. The trip wouldn't have been a notable event, except that the spectrometer, an instrument used to measure the masses of particles, followed a near-9000-kilometer route to get from one town to the other.

To say it was difficult to move the spectrometer would be an understatement. Measuring almost 10 meters at its widest point and weighing 200 tons, the device was too large and too heavy to be transported along the roads between the two towns. Because the design of the detector called for a half-mile of specialized vacuum-tight welding between sheets of stainless steel, it had to be shipped from the Deggendorf site in one piece.

Starting in 2010, the KATRIN experiment will take on the challenge of directly determining the mass of the neutrino, an elusive particle without electric charge. Because neutrinos cannot be detected directly, KATRIN will look for how much mass is missing when tritium decays, a process known to emit neutrinos. To do this, the experiment will rely on the capabilities of the specially-designed large spectrometer.

As it traversed the course of its European odyssey, a team of a dozen scientists fretted over the spectrometer's every move. They watched, guided, worried, and then celebrated when, having navigated a carefully choreographed route across water and land, the instrument finally arrived in Karlsruhe after 63 days of travel.

1 September 28, 2006: The spectrometer began its journey on the river barge "Taifun," shoving off from Deggendorf along the Danube.

2 October 5, 2006: With only seven centimeters to spare, the spectrometer barely slipped under a bridge at the Jochenstein lock in Austria. The barge continued its trip along the Danube through Hungary, Croatia, Serbia, and to the river delta on the Romanian coast without incident.

3 October 31, 2006: After transferring to the sea-going ship Annegret at the Danube Delta in mid-October, the spectrometer left the port of Constanta for the Black Sea.

4 November 6, 2006: The spectrometer was exposed after a storm tore away the instrument's half-ton plastic cover—the trip's only hiccup. Here, at the port of Augusta in Sicily, the instrument was transferred to the Svenja, which carried it around Spain and France to the estuary of the Rhine.

5 Morning, November 25, 2006: On the Rhine, the spectrometer was transferred to a pontoon boat for unloading at the village of Leopoldshafen. A heavy crane, one of two in all of Europe large enough for the task, lifted the spectrometer from the boat to a vehicle waiting at the dock.

6 Afternoon, November 25, 2006: Perched on a large carrier vehicle, the spectrometer, like a displaced spaceship wedged between homes, made its way to the Karlsruhe Research Center through Leopoldshafen.

7 November 29, 2006: The crane, reassembled at the research center, lifted the instrument to its final position through an open roof, bringing the spectrometer's journey to an end.

Text: Alison Drain
Images courtesy of Karlsruhe Research Center

essay: jennifer ouellette

Photos courtesy of Jennifer Ouellette and Penguin Books

Beginner's mind

Several years ago I earned my black belt in jujitsu. Before tying the belt around my waist, the grand master had me don my old white belt, which designates a beginner. He then instructed me to look into a mirror and reflect on what it had been like to walk onto the dojo mat for the first time. The reasoning behind the ceremony is that in order to effectively teach a beginner any given technique, an instructor must be able to break it down into its most basic components. Ergo, it's vital to remember what it was like to know nothing about the technique at all.

The same is true when it comes to communicating science. In my experience, the majority of researchers overestimate how much science—especially physics—the general public is able to absorb in one fell swoop, and they quickly become frustrated at the level of ignorance they routinely encounter outside their rarefied professional circle. The current knowledge gap between scientists and the general public could more accurately be termed a yawning chasm. Cue the all-too-familiar hand-wringing about the sad state of science education in this country. In fairness to the public, more often than not, physicists forget what it was like not having a PhD in their field. They lack "beginner's mind."

Consider all the science people need to know just to comprehend why there is no cause for alarm in the "mini-black holes could destroy the universe" scenario associated with the RHIC facility and the Large Hadron Collider. The average citizen has a rudimentary grasp of black holes, thanks to popular science authors and the seeping of the notion into popular culture. But they probably know almost nothing about Hawking radiation, matter and antimatter, virtual particles, energy conservation, and energy/mass conversion, all of which is necessary to fully comprehend why mini-black holes pose little danger. It seems rather a lot to ask of the average nonscientist, especially if they're distracted by the season premiere of *Grey's Anatomy*.

So how do we reach them? *Grey's Anatomy* and other elements of popular culture just might be able to help. It's easier for nonscientists to grasp an essential physics concept if they can fit it into a familiar context, whether it is a TV show, movie, book, cell phone, iPod, sport, or hobby. This has led to a rash of books on *The Physics of (Blank)*, a genre boosted by the 1995 publication of Lawrence Krauss' *The Physics of Star Trek*. Magazine articles detailing the science behind origami, traffic jams, and other common experiences are equally abundant. It's a highly effective strategy for getting general readers to learn a little science.

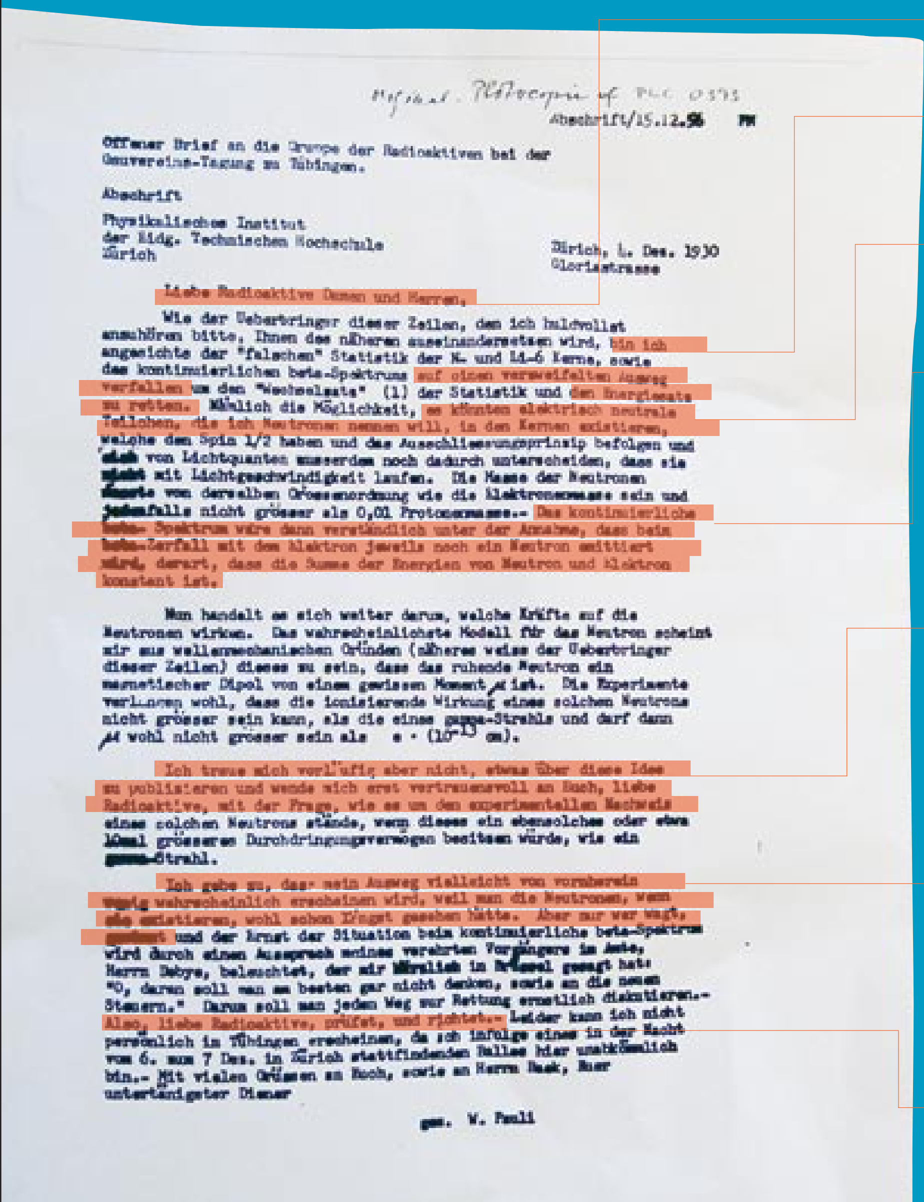
However, in the scientific community, such an approach is frequently derided as a "dumbing down" of science. This is not an entirely unfounded criticism. Certainly my own books occasionally oversimplify concepts to a point that seems ludicrous to PhD scientists, who are accustomed to far meatier fare. But they are not my target audience. You don't serve a starving person an eight-course gourmet meal they can't even begin to digest. You must wean them back onto solid food beginning with tiny bites of bread or crackers, alternating with small sips of water.

In the same way, to reach a broader target audience, you've got to break the science down into manageable bites. To someone accustomed to sampling the full smörgåsbord of scientific delights, dry bread and water would indeed be an insultingly meager repast. But to the starving person, it provides just the right amount of sustenance to prepare them for one day being able to consume an actual meal.

Once we've weaned the public onto more solid fare, we hope they're going to want to explore more substantial options on the menu at their leisure. But before they can embark on that journey of discovery, they must take those first baby steps. They won't do that unless we find some way to ignite their curiosity by showing them how science is relevant to things they already care about.

So however tempting it might be to roll your eyes in disdain the next time someone asks if quantum computing will enable us to communicate with aliens, practice a little patience. Remember when you used to know nothing about science, and break down your response into the most basic components. Foster beginner's mind.

Jennifer Ouellette is a freelance science writer based in Los Angeles, California. She is the author of The Physics of the Buffyverse *(Penguin, 2007) and* Black Bodies and Quantum Cats: Tales from the Annals of Physics *(Penguin, 2006). She also blogs about science and culture at* Cocktail Party Physics*: http://www.twistedphysics.typepad.com.*



Original. Photocopie of PLC 0393

Abschrift/15.12.56 PM

Offener Brief an die Gruppe der Radioaktiven bei der Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grössenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

Nun handelt es sich weiter darum, welche Kräfte auf die Neutronen wirken. Das wahrscheinlichste Modell für das Neutron scheint mir aus wellenmechanischen Gründen (näheres weiss der Ueberbringer dieser Zeilen) dieses zu sein, dass das ruhende Neutron ein magnetischer Dipol von einem gewissen Moment μ ist. Die Experimente verlangen wohl, dass die ionisierende Wirkung eines solchen Neutrons nicht grösser sein kann, als die eines gamma-Strahls und darf dann μ wohl nicht grösser sein als $e \cdot (10^{-13}$ cm).

Ich traue mich vorläufig aber nicht, etwas über diese Idee zu publizieren und wende mich erst vertrauensvoll an Euch, liebe Radioaktive, mit der Frage, wie es um den experimentellen Nachweis eines solchen Neutrons stände, wenn dieses ein ebensolches oder etwa 10mal grösseres Durchdringungsvermögen besitzen würde, wie ein gamma-Strahl.

Ich gebe zu, dass mein Ausweg vielleicht von vornherein wenig wahrscheinlich erscheinen wird, weil man die Neutronen, wenn sie existieren, wohl schon längst gesehen hätte. Aber nur wer wagt, gewinnt und der Ernst der Situation beim kontinuierliche beta-Spektrum wird durch einen Ausspruch meines verehrten Vorgängers im Amte, Herrn Debye, beleuchtet, der mir kürzlich in Brüssel gesagt hat: "O, daran soll man am besten gar nicht denken, sowie an die neuen Steuern." Darum soll man jeden Weg zur Rettung ernstlich diskutieren.- Also, liebe Radioaktive, prüfet, und richtet.- Leider kann ich nicht persönlich in Tübingen erscheinen, da ich infolge eines in der Nacht vom 6. zum 7 Dez. in Zürich stattfindenden Balles hier unabkömmlich bin.- Mit vielen Grüssen an Euch, sowie an Herrn Back, Euer untertänigster Diener

gez. W. Pauli

Image courtesy of the Pauli Letter Collection, CERN. Printed with permission.

Dear Radioactive Ladies and Gentlemen!

I have hit upon a desperate remedy to save…the law of conservation of energy.

…there could exist electrically neutral particles, which I will call neutrons, in the nuclei…

The continuous beta spectrum would then make sense with the assumption that in beta decay, in addition to the electron, a neutron is emitted such that the sum of the energies of neutron and electron is constant.

But so far I do not dare to publish anything about this idea, and trustfully turn first to you, dear radioactive ones, with the question of how likely it is to find experimental evidence for such a neutron…

I admit that my remedy may seem almost improbable because one probably would have seen those neutrons, if they exist, for a long time. But nothing ventured, nothing gained…

Thus, dear radioactive ones, scrutinize and judge.

Translation: Kurt Riesselmann
A complete translation of the letter is available online at www.symmetrymag.org

Wolfgang Pauli, at age 30, had a bold idea on how to solve a perplexing problem in nuclear physics. To explain the apparent disappearance of energy in the decay of certain atomic nuclei, he postulated the existence of a neutral, light-weight particle, saving the fundamental law of the conservation of energy. Pauli proposed that "neutrons" could emerge from decay processes, carrying away energy while escaping direct experimental detection.

Worried that nobody would ever be able to observe this particle, Pauli did not dare to publish his invention without consulting some experimental physicists. On December 4, 1930, Pauli wrote an open letter to a group of nuclear physicists, the "dear radioactive ladies and gentlemen," who were going to meet a few days later in Tübingen, Germany. The document shown here is a machine-typed copy that Pauli obtained in 1956 from Lise Meitner, a well-regarded scientist who had attended the Tübingen meeting.

In the early 1930s, scientists elaborated on Pauli's idea and concluded that the new particle must be extremely light and very weakly interacting. When James Chadwick discovered a neutral particle in 1932, it received the name neutron. But the particle turned out to be too heavy to fit Pauli's prediction. Enrico Fermi, developing a theory of weakly interacting particles, introduced a new name for Pauli's particle: neutrino, which means "little neutral one." A quarter-century later, scientists observed for the first time collisions of neutrinos with matter, the long-sought-after evidence for Pauli's ghost-like invention.

Kurt Riesselmann

explain it in 60 seconds

Dark matter is, mildly speaking, a very strange form of matter. Although it has mass, it does not interact with everyday objects and it passes straight through our bodies. Physicists call the matter dark because it is invisible.

Yet, we know it exists. Because dark matter has mass, it exerts a gravitational pull. It causes galaxies and clusters of galaxies to develop and hold together. If it weren't for dark matter, our galaxy would not exist as we know it, and human life would not have developed.

Dark matter is more than five times as abundant as all the matter we have detected so far. As cosmologist Sean Carroll says, "Most of the universe can't even be bothered to interact with you."

Whatever dark matter is, it is not made of any of the particles we have ever detected in experiments. Dark matter could have—at the subatomic level—very weak interactions with normal matter, but physicists have not yet been able to observe those interactions.

Experiments around the world are trying to detect and study dark matter particles in more direct ways. Facilities like the Large Hadron Collider could create dark matter particles.

Marusa Bradac, Kavli Institute for Particle Astrophysics and Cosmology

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