the world, including the Canary Islands, Chile, and a telescope in Arizona—hoping what they had was a dying, unimaginably distant star. If not, they moved on to the next object. When they found something it was Hook's job to decide if the spectrum they got was indeed a supernova. With the whole team looking over her shoulder, she had a few minutes to give a thumbs up or down. When nothing was going on, Hook played rock and roll loud to keep them going through the night—Verve, maybe, or Radiohead. "I'll never forget the first supernova," recalled Hook. "It was at 1.4 redshift, not terribly high compared to what we get now, but it was such a beautiful spectrum and you could see every detail. There's no question that it was a Type I-A supernova. I mean it looked so good, it guarantees the project works." The image looked like a Mondrian painting. "Since then, we've been getting really good spectra at higher redshifts where no one has gone before. I think to the earlier generation (of astronomers), it seems sort of magic."

With restored funding from the National Science Foundation, Perlmutter hired a few more postdocs and graduate students. The team now totaled twenty; they had "a presence." Some began giving papers at conferences. The Berkeley lab increased its support. At the end of a Keck telescope run, they would take time off to swim at Hapuna Beach, laughing and choking on salt water. At the end of the whole run, everyone came back to Berkeley from their distant locations—Chile, Hawaii, Tucson. They gathered at the home of Gerson Goldhaber and held a party. For each supernova they found, they cracked open a bottle of champagne . . . eventually working up to twenty bottles.

Success stiffened the competition, however, from inside and out. From inside, Carl Pennypacker realized there was no room for two group leaders and decided to pursue a project he had been thinking about a long time. He wanted to bring in public high-school students to work with the raw data the group used, giving students the thrill of cutting-edge discovery. Winning support from the National Science Foundation and the Department of Energy, he began the "Hands-On Universe" program. He sent their data to California high schools by Iternet, where students analyzed it virtually at the same time astronomers did. Students began discovering objects like new asteroids from the information, giving them a bit of the rush Pennypacker first felt doing his math proof as a sixth grader. He remained a member of the Supernova Cosmology Project, but turned over its leadership to Perlmutter.

From outside, a rival international team of astronomers began copying their technology to compete with them. Calling themselves the High Z Supernova Project (Z stands for redshift), they claimed to be a looser, more sophisticated collaboration. They would pay closer attention to the nuances—the precise filters and corrections needed to understand the exact nature of the spectacles they were seeing. They would gather less data but analyze it more carefully. Rather than cookie-cutter physics, they would practice real *astronomy*. Alexei Filippenko defected to join this group, led by none other than Harvard's Robert P. Kirshner and his former student Brian Schmidt. "The other group took pride in the fact that they didn't know anything about the folklore of the field," said Kirshner. "Brian felt we could do what they were doing, only better."

Both groups were pioneering a new astronomy combining "big telescopes, great communications, and great computing power," said Filippenko. Several other projects were also practicing this kind of interdisciplinary cosmology. The Sloan Digital Sky Survey was using robotics and computers to provide the first three-dimensional map of the entire universe with a sky search that, like Perlmutter's work, would be available immediately to amateurs by the Internet. Using new robotics, cheap materials, software, and basic artificial intelligence systems, NASA and the European Space Agency were planning several deep space probes to explore the universe's beginning. NASA's MAP (Microwave Anisotropy Probe) and the European Planck satellites, for instance, would in 2005 and 2007 map in minute detail the ripples in the cosmic background radiation—the echo of the Big Bang. Like the supernova projects, these linked particle physics with deep space astronomy by exploring how protons, neutrons, and electrons first formed out of the cosmic soup.

"We're at the beginning of a new astronomy," said Alan Guth, the MIT theorist who in 1979 wedded cosmology and physics with his theory of inflation—that the universe expanded exponentially in the first fraction of a second. Now astronomy was trying to understand what the universe was like in every moment of its growth. "When I was younger I thought these parameters were unknowable forever. Now they're within our grasp. It's amazing. It really is."

Perlmutter had not invented the opportunistic, shotgun approach, but the international team he directed had made it work. But if the supernova cosmologists felt vindicated, they also now felt the hot breath of others gaining on them.

3

In September 1997, sitting in his cramped office in Berkeley, Gerson Goldhaber was studying the group's data points, the end product of months and years of work and dreaming. On graph paper he had plotted points from all thirty-eight supernovae. He routinely looked at the grouping to anticipate what they were learning about the age and future of the universe. For months he had noticed that all the supernovae were piling up at the lower end of the scale, meaning they were farther away and farther back in time than commonly accepted theories of cosmic expansion would have predicted. He kept thinking that the bunch would spread out as their precision improved. Instead what he now saw was a giant spike, almost exactly like the spike he had seen forty years earlier when he discovered the fundamental particle called the mu meson. He nearly jumped out of his chair.

What the spike showed was that, far from decelerating as all the astronomy texts claimed, the universe was actually accelerating. This acceleration had been suggested by only one person, Albert Einstein, who called it lambda and used it to counteract relativity's prediction that the universe should collapse on itself. Einstein quickly abandoned lambda as being a preposterous cosmic fudge factor. But the data Goldhaber was examining said they were seeing some kind of universal constant, a mystery engine driving the cosmos. At a hastily convened meeting on September 24 they argued into the evening. Several on the team urged caution. They were just getting legitimate acclaim. They dare not blow it on such an outrageous finding. Better to wait, gather more information. "Gerson says he will keep working on this," the minutes of the meeting read. Then, in italics, Goldhaber was quoted as saying, *"I've been known to make mistakes."*

In December 1997 Saul Perlmutter was staying up all night at the Keck Observatory. Taking camcorder pictures of the sky from the peak of Hawaii's tallest mountain was a lonely job. Oxygen was only 60 percent of that at sea level and the night sky, stretching over the observatory's twin domes, disoriented viewers at three in the morning. He had a constant headache. Every so often the telescope operator put on his down jacket, went outside, and slid through the snow to look up and check that the three-hundred-ton machine was pointing out above the clouds. Steam rose from a volcano. Above him, seven-billion-year-old starlight roiled and spun. They worked all night and caught a few hours of sleep in the day.

Perlmutter and Hook again worked frantically, analyzing the images and directing where to point the telescope with nanometer precision. Ever since their meeting with Goldhaber their work had a new urgency. Perlmutter was going to present their findings at the biggest science conference in the world, the American Astronomical Society (AAS) conference in January in Washington. What would he say? He e-mailed the targets to the Canary Islands, Chile, Arizona, and California, and ultimately to the Hubble itself. Then they waited anxiously. Isobel Hook had a few seconds to analyze each image from the top of the mountain. They argued, talking with the telescope operator by video teleconferencer. When she had some time, Hook liked to go outside and look up at the starlight coming from the edges of the universe, all the way to where she stood at the volcano's bottom in a breeze that smelled of bougainvillea.

Perlmutter dropped the phone to check the computer screens again. Hook and Perlmutter decided when they had a good spot, assigning the greatest telescope in history, the Hubble Space Telescope in orbit two-hundred-forty-five miles above them, to look at a distant smudge of a star in the throes of death. Using this approach to detect supernovae on the fly and transmitting this information around the world instantly, they were coming close to realizing their dream.

They were also racing another group. They plotted their findings on a graph, matching the distance of the stellar explosions against their velocity as they were swept away by cosmic expansion. Their data made for a perplexing line. Everyone was buzzing about it at Hapuna Beach on their last day. The line curved up at its end, as Goldhaber had suggested, meaning that indeed the universe was not decelerating as all the texts said, but was *accelerating*. If it was real it would make the announcement of a lifetime. But their uncertainty was high; too many things could be wrong. Did they have the correct color measurements? Why did their analysis now disagree so much with an earlier one? Perlmutter caught a flight to Berkeley, where he had a morning layover to race to the lab, run the numbers, print out a poster, and race back to the airport, where he hopped a plane to Washington, D.C. with the graph stuffed in his briefcase, heading to the annual meeting of the American Astronomical Society.

I saw him present his findings that January. He was disheveled, having just jumped off the plane after staying up all night. From devices as common as the light detectors used in camcorders and the Internet, he said, they had evidence suggesting that, contrary to theory, the universe would expand forever into a lonely infinite night. Reporters mobbed him afterward.

Surrounded in the press room of the Georgetown Hilton, Saul Perlmutter was the star of the AAS meeting. He was offering a possible solution to one of the biggest questions of cosmology. Fortunately, four other researchers on his panel, using more conventional methods, had gotten roughly the same result. After he gave his talk, reporters clustered around him for an hour, asking question after question. How could you take the Hubble, writers asked, steer it into position, and watch the death of a star lasting all of three weeks, from seven billion years ago?

It was a great place to report findings because the funding directors of the National Science Foundation and the Center for Astrophysics were all there. Their story played not just in *The New York Times,* but in newspapers and on TV news all over the country. It was enormous news, telling us that "some kind of new physics is happening now," Princeton astrophysicist David Spergel told *The Washington Post.* Perlmutter discovered that he possessed the traditional cosmological talent for publicity.

But he chose to play down their more spectacular results. One reporter, James Glanz from *Science,* commented on the implied cosmic acceleration in their data while two others hinted at it later. In the hall afterward I joined Perlmutter as he hung out with some of the other young astronomers, still happy to answer questions, checking out what they were doing. For the rest of their lives, however, some in his small group would question their caution.

4

The following month a much smaller meeting was scheduled at Marina Del Rey in California. There both supernova groups were to speak. Acceleration, the idea that objects in space were moving faster and faster away from each other was a monumental discovery, on the order of Edwin Hubble's first observation, in 1927, that the universe was expanding. If the universe was accelerating, the entire foundation of physics was shaky. It meant a completely unknown force or energy was at work.

The problem for the Perlmutter team was that their margin of error, or error bars, were still too great, they felt, to make such a stupendous announcement. But the competing group now had had access to their data since it had been announced. What should they do? At Marina del Rey Perlmutter showed their data with the error bars, saying they had "evidence" for acceleration but not proof.

Then Alex Filippenko rose to address the group. Well, he began, savoring the moment, either you have a discovery or you don't. We have evidence, and our error bars are much smaller and better understood. We have for the first time real evidence of a new "antigravity" force at work in the cosmos.

Afterward a commotion broke in the conference room. Again it was James Glanz of *Science* who got the story first, though other journalists soon followed. The curve on the top of the High Z graph pushed the cradle of physics off a cliff. "Somewhere between amazement and horror," said High Z coleader Brian Schmidt of the Mount Tromlo and Sliding Spring Observatory in Australia. "Magical," said Michael Turner, theorist of the University of Chicago. "It's crazy," said colleague Rocky Kolb, who compared the discovery of the missing matter in the universe to the Marx brothers movie in which more and more people crowd into a stateroom, leading to chaos.

If the universe was expanding faster and faster, not only were the texts wrong, but something like 70 percent of the universe's energy was missing. This mysterious energy was driving the unheard-of acceleration. The finding was so amazing that many theorists balked, rightfully so. "Extraordinary claims require extraordinary evidence," cautioned Turner. "The competitive urges," added another theorist, "have driven both these groups out onto a limb where they shouldn't be."

While the two teams set to work on supporting their claim, Alex Filippenko had to take off for a long-scheduled eclipse cruise, mostly for retired couples. It was fitting that the youngest member of the High Z team, the soccer-playing Adam Riess, suddenly found himself on the "McNeil-Lehrer News Hour" (his father's favorite show), discussing the meaning of space and time. "(They) asked me, 'Why should people care about this?'" Reiss recalled. "I said, well, 'Why am I on this show?'" Riess had done most of the grunt work. For once a postdoctoral jobseeker got the acclaim. Younger than any other group member, Riess was proof of a new astronomy taking hold. "This was something most of us thought we would just never know," he said, echoing Guth's words.

As for the Perlmutter team, after all their work, all the rejection, the criticisms leveled against them rankled: they were *too* bold or *not* bold enough, and in either case they were mere physicists, too sloppy for the finely nuanced art of astronomy. Kirshner gave them no credit in his discussions in the press, even though it was their method that made the discovery possible. "He got the credit because he came from Harvard," complained Pennypacker. "They have better press agents," said the normally equable Gerson Goldhaber. The bad blood between them, embarrassing for all, became even, well, badder.

"Hey, what's the strongest force in the universe?" Kirshner told *The New York Times*. "It's not gravity, it's jealousy." Photographed in front of the august Harvard-Smithsonian Center for Astrophysics, he grinned in triumph.

5

The announcements of the findings had stirred up so much puzzlement and sheer disbelief that Perlmutter, Riess, and Kirshner were all called to a showdown at a conference in May 1998 at the Fermi National Accelerator Laboratory. In the Illinois prairie, theorists and experimenters came together for a gathering called "Where Is the Missing Energy?" The theorists were desperate to question and challenge the findings, and to know more. The giant particle accelerator at Fermilab provided a fitting backdrop, because it was the machine that solidified the last piece of the Standard Model of physics and the cosmos.

While cicadas chimed outside, researchers grappled with the discoveries. If, as most thought, the cosmic soup had exploded exponentially in the Big Bang, doubling in size every instant in its first trillionth of a second, it seemed as though, for its first seven billion years, the universe had indeed been slowing down. The evidence from the supernovae experiments suggested, however, that at a critical point, when the density had lessened, another repelling force had kicked in, pushing matter out faster and faster.

The force seemed to be Einstein's famous "cosmological constant," added in 1917 to his theory of general relativity. Einstein added it because relativity seemed to predict the universe should collapse under its own weight. When Edwin Hubble discovered the expanding universe, Einstein discarded his constant as "the greatest blunder of my career." Now it was resurrected. If the universe was accelerating, some previously unknown enormous energy existed.

Was the missing energy Einstein's cosmological constant, or something more dynamic that varied over time? "It's a monumental issue," said Princeton's Paul Steinhardt. "It means a significant fraction of what's out there we weren't even thinking about a few years ago. That's why it's particularly important to understand whether it's something fairly uniform and static, or something dynamical and changing. It's monumental both for fundamental physics and for cosmology."

What was going on? Steinhardt called the missing energy "quintessence," after Aristotle's fifth element. Quintessence was fundamental mystery, a roadblock that seemed a precursor to a radical shift in scientific thought. Was quintessence the same as dark matter, the unseen stuff that seemed to clamp down on galaxies like a waffle iron? It seemed not. It appeared rather, that this energy or force had an effect only after some seven billion years, during which time the expansion did decelerate as standard theory predicted. Once the density of the universe fell below a certain point, however, the "antigravity force" kicked in—suddenly revving up the outward explosion of all matter. The answer lay in supernovae evidence. "Not only would it tell us what the universe is composed of, where it came from, and where it's going, but it would tie together the laws of physics," Paul Steinhardt said to reporters at a special luncheon at Fermilab. Over the clacking of plastic forks and whirring of tape recorders, he said: "It must emerge from a fundamental law of physics, and we need to know which form it is, not only for cosmology, but for people who are trying to develop the holiest grail of all—unified theories of fundamental forces. You have a new ingredient that you had not anticipated suddenly forced upon you." Endorsing the new interdisciplinary approach, he added: "It's an opportunity for cosmology to provide a gift to particle physics."

Within a few months the ground would shift once again, as more observations plotted on neat graphs, shown on overhead transparencies, and reproduced in *Science* and popular newspapers confirmed that the universe began to accelerate about halfway through its 14.2-billion-year history. What was this exotic energy that opposed the natural self-attractive gravity of matter? Whatever the answer, the two supernovae teams had taken the search for the true nature of the cosmos out of the realm of philosophy and into that of science. "In science you usually have a tradition you must match," said Perlmutter. "Do your data fit the tradition? In this field, there is no tradition, no previous data. It's completely uncharted."

At the end of the Fermilab meeting, while Telemann from a state high-school flute competition echoed in Fermilab's great hall,