Out There

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Three days after learning that he won the 2006 Nobel Prize in Physics, George Smoot was talking about the universe. Sitting across from him in his office at the University of California, Berkeley, was Saul Perlmutter, a fellow cosmologist and a probable future Nobelist in Physics himself. Bearded, booming, eyes pinwheeling from adrenaline and lack of sleep, Smoot leaned back in his chair. Perlmutter, onetime acolyte, longtime colleague, now heir apparent, leaned forward in his.

“Time and time again,” Smoot shouted, “the universe has turned out to be really simple.”

Perlmutter nodded eagerly. “It’s like, why are we able to understand the universe at our level?”

“Right. Exactly. It’s a universe for beginners! ‘The Universe for Dummies’!”

But as Smoot and Perlmutter know, it is also inarguably a universe for Nobelists, and one that in the past decade has become exponentially more complicated. Since the invention of the telescope four centuries ago, astronomers have been able to figure out the workings of the universe simply by observing the heavens and applying some math, and vice versa. Take the discovery of moons, planets, stars and galaxies, apply Newton’s laws and you have a universe that runs like clockwork. Take Einstein’s modifications of Newton, apply the discovery of an expanding universe and you get the big bang. “It’s a ridiculously simple, intentionally cartoonish picture,” Perlmutter said. “We’re just incredibly lucky that that first try has matched so well.”

But is our luck about to run out? Smoot's and Perlmutter's work is part of a revolution that has forced their colleagues to confront a universe wholly unlike any they have ever known, one that is made of only 4 percent of the kind of matter we have always assumed it to be — the material that makes up you and me and this magazine and all the planets and stars in our galaxy and in all 125 billion galaxies beyond. The rest — 96 percent of the universe — is ... who knows?

"Dark," cosmologists call it, in what could go down in history as the ultimate semantic surrender. This is not "dark" as in distant or invisible. This is "dark" as in unknown for now, and possibly forever.

If so, such a development would presumably not be without philosophical consequences of the civilization-altering variety. Cosmologists often refer to this possibility as "the ultimate Copernican revolution": not only are we not at the center of anything; we're not even made of the same stuff as most of the rest of everything. "We're just a bit of pollution," Lawrence M. Krauss, a theorist at Case Western Reserve, said not long ago at a public panel on cosmology in Chicago. "If you got rid of us, and all the stars and all the galaxies and all the planets and all the aliens and everybody, then the universe would be largely the same. We're completely irrelevant."

All well and good. Science is full of homo sapiens-humbling insights. But the trade-off for these lessons in insignificance has always been that at least now we would have a deeper — simpler — understanding of the universe. That the more we could observe, the more we would know. But what about the less we could observe? What happens to new knowledge then? It's a question cosmologists have been asking themselves lately, and it might well be a question we'll all be asking ourselves soon, because if they're right, then the time has come to rethink a fundamental assumption: When we look up at the night sky, we're seeing the universe.

Not so. Not even close.

In 1963, two scientists at Bell Labs in New Jersey discovered a microwave signal that came from every direction of the heavens. Theorists at nearby Princeton University soon realized that this signal might be the echo from the beginning of the universe, as predicted by the big-bang hypothesis. Take the idea of a cosmos born in a primordial fireball and cooling down ever since, apply the discovery of a microwave signal with a temperature that corresponded precisely to the one that was predicted by theorists — 2.7 degrees above absolute zero — and you have the universe as we know it. Not Newton's universe, with its stately, eternal procession of benign objects, but Einstein's universe, violent, evolving, full of births and deaths, with the grandest birth and, maybe, death belonging to the cosmos itself.

But then, in the 1970s, astronomers began noticing something that didn't seem to fit with the laws of physics. They found that spiral galaxies like our own Milky Way were spinning at such a rate that they should have long ago wobbled out of control, shredding apart, shedding stars in every direction. Yet clearly they had done no such thing. They were living fast but not dying young. This seeming paradox led theorists to wonder if a halo of a hypothetical something else might be cocooning each galaxy, dwarfing each flat spiral disk of stars and gas at just the right mass ratio to keep it gravitationally intact. Borrowing a term from the astronomer Fritz Zwicky, who detected the same problem with the motions of a whole cluster of galaxies back in the 1930s, decades before anyone else took the situation seriously, astronomers called this mystery mass “dark matter.”

So there was more to the universe than meets the eye. But how much more? This was the question Saul Perlmutter’s team at Lawrence Berkeley National Laboratory set out to answer in the late 1980s. Actually, they wanted to settle an issue that had been nagging astronomers ever since Edwin Hubble discovered in 1929 that the universe seems to be expanding. Gravity, astronomers figured, would be slowing the expansion, and the more matter the greater the gravitational effect. But was the amount of matter in the universe enough to slow the expansion until it eventually stopped, reversed course and collapsed in a backward big bang? Or was the amount of matter not quite enough to do this, in which case the universe would just go on expanding forever? Just how much was the expansion of the universe slowing down?

The tool the team would be using was a specific type of exploding star, or supernova, that reaches a roughly uniform brightness and so can serve as what astronomers call a standard candle. By comparing how bright supernovae appear and how much the expansion of the universe has shifted their light, cosmologists sought to determine the rate of the expansion. “I was trying to tell everybody that this is the measurement that everybody should be doing,” Perlmutter says. “I was trying to convince them that this is going to be the tool of the future.” Perlmutter talks like a microcassette on fast-forward, and he possesses the kind of psychological dexterity that allows him to walk into a room and instantly inhabit each person’s point of view. He can be as persuasive as any force of nature. “The next thing I know,” he says, “we’ve convinced people, and now they’re competing with us!”

By 1997, Perlmutter’s Supernova Cosmology Project and a rival team had amassed data from more than 50 supernovae between them — data that would reveal yet another oddity in the cosmos. Perlmutter noticed that the supernovae weren’t brighter than expected but dimmer. He wondered if he had made a mistake in his observations. A few months later, Adam Riess, a member of a rival international team, noticed the same general drift in his math and wondered the same thing. “I’m a postdoc,” he told himself. “I’m sure I’ve messed up in at least 10 different ways.” But Perlmutter double-checked for intergalactic dust that might have skewed his readings, and Riess cross-checked his math, calculation by calculation, with his team leader, Brian Schmidt. Early in 1998, the two teams announced that they had each independently reached the same conclusion, and it was the opposite of what either of them expected. The rate of the expansion of the universe was not slowing down. Instead, it seemed to be speeding up.

That same year, Michael Turner, the prominent University of Chicago theorist, delivered a paper in which he called this antigravitational force “dark energy.” The purpose of calling it “dark,” he explained recently, was to highlight the similarity to dark matter. The purpose of “energy” was to make a distinction. “It really is very different from dark matter,” Turner said. “It’s more energylike.”

More energylike how, exactly?

Turner raised his eyebrows. “I’m not embarrassed to say it’s the most profound mystery in all of science.”

Extraordinary claims,” Carl Sagan once said, “require extraordinary evidence.” Astronomers love that saying; they quote it all the time. In this case the claim could have hardly been more extraordinary: a new universe was dawning.

It wouldn’t be the first time. We once thought the night sky consisted of the several thousand objects we could see with the naked eye. But the invention of the telescope revealed that it didn’t, and that the farther we saw, the more we saw: planets, stars, galaxies. After that we thought the night sky consisted of only the objects the eye could see with the assistance of telescopes that reached all the way back to the first stars blinking to life. But the discovery of wavelengths beyond the optical revealed that it didn’t, and that the more we saw in the radio or infrared or X-ray parts of the electromagnetic spectrum, the more we discovered: evidence for black holes, the big bang and the distances of supernovae, for starters.

The difference with “dark,” however, is that it lies not only outside the visible but also beyond the entire electromagnetic spectrum. By all indications, it consists of data that our five senses can’t detect other than indirectly. The motions of galaxies don’t make sense unless we infer the existence of dark matter. The brightness of supernovae doesn’t make sense unless we infer the existence of dark energy. It’s not that inference can’t be a powerful tool: an apple falls to the ground, and we infer gravity. But it can also be an incomplete tool: gravity is ... ?

Dark matter is ... ? In the three decades since most astronomers decisively, if reluctantly, accepted the existence of dark matter, observers have eliminated the obvious answer: that dark matter is made of normal matter that is so far away or so dim that it can’t be seen from earth. To account for the dark-matter deficit, this material would have to be so massive and so numerous that we couldn’t possibly miss it.

Which leaves abnormal matter, or what physicists call nonbaryonic matter, meaning that it doesn’t consist of the protons and neutrons of “normal” matter. What’s more (or, perhaps more accurately, less), it doesn’t interact at all with electricity or magnetism, which is why we wouldn’t be able to see it, and it can rarely interact even with protons and neutrons, which is why trillions of these particles might be passing through you every second without your knowing it. Theorists have narrowed the search for dark-matter particles to two hypothetical candidates: the axion and the neutralino. But so far efforts to create one of these ghostly particles in accelerators, which mimic the high levels of energy in the first fraction of a second after the birth of the universe, have come up empty. So have efforts to catch one in ultrasensitive detectors, which number in the dozens around the world.

For now, dark-matter physicists are hanging their hopes on the Large Hadron Collider, the latest-generation subatomic-particle accelerator, which goes online later this year at the European Center for Nuclear Research on the Franco-Swiss border. Many cosmologists think that the L.H.C. has made the creation of a dark-matter particle — as George Smoot said, holding up two fingers — “this close.” But one of the pioneer astronomers investigating dark matter in the 1970s, Vera Rubin, says that she has lived through plenty of this kind of optimism; she herself predicted in 1980 that dark matter would be identified within a decade. “I hope he’s right,” she says of Smoot’s assertion. “But I think it’s more a wish than a belief.” As one particle physicist commented at a “Dark Universe” symposium at the Space Telescope Science Institute in Baltimore a few years ago, “If we fail to see anything in the L.H.C., then I’m off to do something else,” adding, “Unfortunately, I’ll be off to do something else at the same time as hundreds of other physicists.”

Juan Collar might be among them. “I know I speak for a generation of people who have been looking for dark-matter particles since they were grad students,” he said one wintry afternoon in his University of Chicago office. “I doubt how many of us will remain in the field if the L.H.C. brings home bad news. I have been looking for dark-matter particles for more than 15 years. I’m 42. So most of my colleagues, my age, we are kind of going through a midlife crisis.” He laughed. “When we get together and we drink enough beer, we start howling at the moon.”

Although many scientists say that the existence of the axion will be proved or disproved within the next 10 years — as a result of work at Lawrence Livermore National Laboratory — the detection of a neutralino one way or the other is much less certain. A negative result from an experiment might mean only that theorists haven’t thought hard enough or that observers haven’t looked deep enough. “It could very well be that Mother Nature has decided that the neutralino is way down there,” Collar said, pointing not to a graph that he taped up in his office but to a point below the sheet of paper itself, at the blank wall. “If that is the case,” he went on to say, “we should retreat and worship Mother Nature. These particles maybe exist, but we will not see them, our sons will not see them and their sons won’t see them.”

The challenge with dark energy, as opposed to dark matter, is even more difficult. Dark energy is whatever it is that’s making the expansion of the universe accelerate, but, for instance, does it change over time and space? If so, then cosmologists have a name for it: quintessence. Does it not change? In that case, they’ll call it the cosmological constant, a version of the mathematical fudge factor that Einstein originally inserted into the equations for relativity to explain why the universe had neither expanded nor contracted itself out of existence.

After the discovery of dark energy, Perlmutter concluded that the next generation of dark-energy telescopes would have to include a space-based observatory. But the search for financing for such an ambitious project can require as much forbearance as the search for dark energy itself. “I don’t think I’ve ever seen as much of Washington as I have in the last few years,” he says, sighing. Even if his Supernova Acceleration Probe didn’t now face competition from several other proposals for federal financing (including, perhaps inevitably, one involving his old rival Riess), delays have prevented it from being ready to launch until at least the middle of the next decade. “Ten years from now,” says Josh Frieman of the University of Chicago, “when we’re talking about spending on the order of a billion dollars to put something up in space — which I think we should do — you’re getting into that class where you’re spending real money.”

Even some cosmologists have begun to express reservations. At a conference at Durham University in England last summer, a “whither cosmology?” panel featuring some of the field’s most prominent names questioned the wisdom of concentrating so much money and manpower on one problem. They pointed to what happened when the government-sponsored Dark Energy Task Force solicited proposals for experiments a couple of years ago. The task force was expecting a dozen, according to one member. They got three dozen. Cosmology was choosing a “risky and not very cost-effective way of moving forward,” one Durham panelist told me later, summarizing the sentiment he heard there.

But even if somebody were to figure out whether or not dark energy changes across time and space, astronomers still wouldn’t know what dark energy itself is. “The term doesn’t mean anything,” said David Schlegel of Lawrence Berkeley National Laboratory this past fall. “It might not be dark. It might not be energy. The whole name is a placeholder. It’s a placeholder for the description that there’s something funny that was discovered eight years ago now that we don’t understand.” Not that theorists haven’t been trying. “It’s just nonstop,” Perlmutter told me. “There’s article after article after article.” He likes to begin public talks with a PowerPoint illustration: papers on dark energy piling up, one on top of the next, until the on-screen stack ascends into the dozens. All the more reason not to put all of cosmology’s eggs into one research basket, argued the Durham panelists. As one summarized the situation, “We don’t even have a hypothesis to test.”

Michael Turner won’t hear of it. “This is one of these godsend problems!” he says. “If you’re a scientist, you’d like to be around when there’s a great problem to work on and solve. The solution is not obvious, and you could imagine it being solved tomorrow, you could imagine it taking another 10 years or you could imagine it taking another 200 years.”

But you could also imagine it taking forever.

“Time to get serious.” The PowerPoint slide, teal letters popping off a black background, stared back at a hotel ballroom full of cosmologists. They gathered in Chicago last winter for a “New Views of the Universe” conference, and Sean Carroll, then at the University of Chicago, had taken it upon himself to give his theorist colleagues their marching orders.

“There was a heyday for talking out all sorts of crazy ideas,” Carroll, now at Caltech, recently explained. That heyday would have been the heady, post-1998 period when Michael Turner might stand up at a conference and turn to anyone voicing caution and say, “Can’t we be exuberant for a while?” But now has come the metaphorical morning after, and with it a sobering realization: Maybe the universe isn’t simple enough for dummies like us humans. Maybe it’s not just our powers of perception that aren’t up to the task but also our powers of conception. Extraordinary claims like the dawn of a new universe might require extraordinary evidence, but what if that evidence has to be literally beyond the ordinary? Astronomers now realize that dark matter probably involves matter that is nonbaryonic. And whatever it is that dark energy involves, we know it’s not “normal,” either. In that case, maybe this next round of evidence will have to be not only beyond anything we know but also beyond anything we know how to know.

That possibility always gnaws at scientists — what Perlmutter calls “that sense of tentativeness, that we have gotten so far based on so little.” Cosmologists in particular have had to confront that possibility throughout the birth of their science. “At various times in the past 20 years it could have gotten to the point where there was no opportunity for advance,” Frieman says. What if, for instance, researchers couldn’t repeat the 1963 Bell Labs detection of the supposed echo from the big bang? Smoot and John C. Mather of NASA (who shared the Nobel in Physics with Smoot) designed the Cosmic Background Explorer satellite telescope to do just that. COBE looked for extremely subtle differences in temperature throughout all of space that carry the imprint of the universe when it was less than a second old. And in 1992, COBE found them: in effect, the quantum fluctuations that 13.7 billion years later would coalesce into a universe that is 22 percent dark matter, 74 percent dark energy and 4 percent the stuff of us.

And if the right ripples hadn’t shown up? As Frieman puts it: “You just would have thrown up your hands and said, ‘My God, we’ve got to go back to the drawing board!’ What’s remarkable to me is that so far that hasn’t happpened.”

Yet in a way it has. In the observation-and-theory, call-and-response system of investigating nature that scientists have refined over the past 400 years, the dark side of the universe represents a disruption. General relativity helped explain the observations of the expanding universe, which led to the idea of the big bang, which anticipated the observations of the cosmic-microwave background, which led to the revival of Einstein’s cosmological constant, which anticipated the observations of supernovae, which led to dark energy. And dark energy is ... ?

The difficulty in answering that question has led some cosmologists to ask an even deeper question: Does dark energy even exist? Or is it perhaps an inference too far? Cosmologists have another saying they like to cite: “You get to invoke the tooth fairy only once,” meaning dark matter, “but now we have to invoke the tooth fairy twice,” meaning dark energy.

One of the most compelling arguments that cosmologists have for the existence of dark energy (whatever it is) is that unlike earlier inferences that physicists eventually had to abandon — the ether that 19th-century physicists thought pervaded space, for instance — this inference makes mathematical sense. Take Perlmutter's and Riess's observations of supernovae, apply one cornerstone of 20th-century physics, general relativity, and you have a universe that does indeed consist of .26 matter, dark or otherwise, and .74 something that accelerates the expansion. Yet in another way, dark energy doesn't add up. Take the observations of supernovae, apply the other cornerstone of 20th-century physics, quantum theory, and you get gibberish — you get an answer 120 orders of magnitude larger than .74.

Which doesn't mean that dark energy is the ether of our age. But it does mean that its implications extend beyond cosmology to a problem Einstein spent the last 30 years of his life trying to reconcile: how to unify his new physics of the very large (general relativity) with the new physics of the very small (quantum mechanics). What makes the two incompatible — where the physics breaks down — is gravity.

In physics, gravity is the ur-inference. Even Newton admitted that he was making it up as he went along. That a force of attraction might exist between two distant objects, he once wrote in a letter, is "so great an Absurdity that I believe no Man who has in philosophical Matters a competent Faculty of thinking can ever fall into it." Yet fall into it we all do on a daily basis, and physicists are no exception. "I don't think we really understand what gravity is," Vera Rubin says. "So in some sense we're doing an awful lot on something we don't know much about."

It hasn't escaped the notice of astronomers that both dark matter and dark energy involve gravity. Early this year 50 physicists gathered for a "Rethinking Gravity" conference at the University of Arizona to discuss variations on general relativity. "So far, Einstein is coming through with flying colors," says Sean Carroll, who was one of the gravity-defying participants. "He's always smarter than you think he was."

But he's not necessarily inviolate. "We've never tested gravity across the whole universe before," Riess pointed out during a news conference last year. "It may be that there's not really dark energy, that that's a figment of our misperception about gravity, that gravity actually changes the way it operates on long ranges."

The only way out, cosmologists and particle physicists agree, would be a "new physics" — a reconciliation of general relativity and quantum mechanics. "Understanding dark energy," Riess says, "seems to really require understanding and using both of those theories at the same time."

"It's been so hard that we're even willing to consider listening to string theorists," Perlmutter says, referring to work that posits numerous dimensions beyond the traditional (one of time and three of space). "They're at least providing a language in which you can talk about both things at the same time."

According to quantum theory, particles can pop into and out of existence. In that case, maybe the universe itself was born in one such quantum pop. And if one universe can pop into existence, then why not many universes? String theorists say that number could be 10 raised to the power of 500. Those are 10-with-500-zeros universes, give or take. In which case, our universe would just happen to be the one with an energy density of .74, a condition suitable for the existence of creatures that can contemplate their hyper-Copernican existence.

And this is just one of a number of theories that have been popping into existence, quantum-particle-like, in the past few years: parallel universes, intersecting universes or, in the case of Stephen Hawking and Thomas Hertog just last summer, a superposition of universes. But what evidence — extraordinary or otherwise — can anyone offer for such claims? The challenge is to devise an experiment that would do for a new physics what COBE did for the big bang. Predictions in string theory, as in the 10-to-the-power-of-500-universes hypothesis, depend on the existence of extra dimensions, a stipulation that just might put the burden back on particle physics — specifically, the hope that evidence of extra dimensions will emerge in the Large Hadron Collider, or perhaps in its proposed successor, the International Linear Collider, which might come online sometime around 2020, or maybe in the supercollider after that, if the industrial nations of 2030 decide they can afford it.

“You want your mind to be boggled,” Perlmutter says. “That is a pleasure in and of itself. And it’s more a pleasure if it’s boggled by something that you can then demonstrate is really, really true.”

And if you can’t demonstrate that it’s really, really true?

“If the brilliant idea doesn’t come along,” Riess says, “then we will say dark energy has exactly these properties, it acts exactly like this. And then” — a shrug — “we will put it in a box.” And there it will remain, residing perhaps not far from the box labeled “Dark Matter,” and the two of them bookending the biggest box of them all, “Gravity,” to await a future Newton or Einstein to open — or not.

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