BY STUDYING BOTH THE TINIEST AND MOST MASSIVE
PUSHES THE FRONT LINES OF PHYSICS RESEARCH

PHENOMENA, A PIONEERING CENTER

BY JASON HOLLANDER / GAL '07

LOCATED NEAR GENEVA, SWITZERLAND, THE 27-KILOMETER, $6 BILLION LARGE HADRON COLLIDER WILL ALLOW SCIENTISTS TO SIMULATE THE MOMENTS JUST AFTER THE BIG BANG—THE "BIRTH" OF THE UNIVERSE 13.7 BILLION YEARS AGO.

FOR SOME KIDS, AGE 10 IS WHEN THEY START TO MEMORIZE PLAYERS ON THEIR FAVORITE BASEBALL TEAM OR GROW OBSESSED WITH A CERTAIN CARTOON OR VIDEO GAME. FOR DAVID W. HOGG, 10 IS WHEN HE FIRST BECAME AWARE THAT "WE LIVE ON AN ABSOLUTELY, MICROSCOPICALLY INSIGNIFICANT FLECK OF DUST IN THE MIDDLE OF NOWHERE IN THIS GINORMOUS UNIVERSE." IT MIGHT SOUND LIKE THE SETUP FOR A WOODY ALLEN PROTAGONIST, BUT THE REALIZATION CAST A LINGERING SPELL ON HIM. NO ONE—NOT HIS PARENTS, TEACHERS, OR FRIENDS—COULD PROVIDE RELIEF FROM THE UTTER FEAR BROUGHT ON BY IT. OUT OF NECESSITY, YOUNG HOGG FINALLY SETTLED ON A CREED: "THE FACT IS, WE *ARE* COMPLETELY INSIGNIFICANT. SUCK IT UP."

But he didn't stick to that. Instead, Hogg, now 39, eventually channeled his distress into the search for a more precise and, perhaps, *significant* understanding of our place in the cosmos.

This colossal pursuit is shared by his colleagues at NYU's Center for Cosmology and Particle Physics, or CCPP. The 11 professors, 11 postdoctoral researchers, and 20 graduate students in CCPP are members of the world's first center to formally merge the study of fundamental (concerned with the smallest particles) and grand-scale physics (focused on celestial bodies)—with the hopes that this cross-pollination will help reveal the elusive mysteries of space and time. Teams at CCPP are behind some of the field's most provocative theories and projects, aspiring to find evidence of extra dimensions, explain dark matter and dark energy, create micro black holes, and build the largest three-dimensional map of the universe ever made.

It's okay if the last couple of sentences don't resonate. It means you're among the 99.9 percent who aren't versed in physics talk. So here's a quick primer: Particle, or fundamental, physics examines the essential elements of the universe. These include photons, electrons, and the subatomic particles that comprise protons and neutrons. Research in the properties of these particles has established Quantum Mechanics—the accepted set of laws for the microscopic world. Cosmology, on the other hand, is concerned with the physics of the largest structures in the universe—galaxies, and their clusters or superclusters—and is still much rooted in Albert Einstein's General Theory of Relativity. As of yet, the fields are scientifically incompatible because the natural laws of each realm don't match up.

Now take these two seemingly antithetical areas of study, crisscross them intellectually, experimentally, socially, and philosophically, and you get CCPP. The center has experts from both arenas working side-by-side on big-picture questions. As a result, from its tiny home base in Greenwich Village, NYU has become a major player in the largest experiments being conducted from Switzerland to Argentina and beyond.

The creation of CCPP required the vision of someone who could see past walls. Glennys Farrar became the first woman to earn a PhD in physics from Princeton University in 1971 and still remembers her grad school admissions interview there, when she was asked, "Why, in spite of being a woman, they should admit me." So when the professor came from Rutgers University to NYU in 1998, she was impressed to see the cosmologists hanging out and debating with the particle gurus—at lunch, after lectures, in the halls. This fit her notion that most physics departments "shoot themselves in the foot" by keeping their faculty in separate silos. "It was clear to me that the underlying, important questions were entangled," says Farrar, who found the Faculty of Arts and Science administration immediately receptive when she pitched the idea for the center in 2001.

As the director of CCPP from its inception to 2008, Farrar wanted to attract the world's most talented scientists and, ironically, it was an expan-

sive, nonacademic space in its home on the fifth floor of Meyer Hall that helped to lure them. With oversize windows, funky couches and stools, and a treasured espresso maker, the CCPP lounge could pass for a typical Village coffeehouse, but the per capita PhDs and the algorithms on the communal chalkboard are a giveaway that this isn't Caffe Reggio. And at lunchtime, just about everyone emerges from his or her office to sit together and talk about everything from physics to baseball—and sometimes the physics of baseball. For Hogg, who was recruited as an assistant professor in 2001 along with several others from the prestigious Institute for Advanced Study in Princeton, the sense of community that existed even before the center came to be was a huge draw. "In a lot of disciplines a scholar is rewarded for isolating himself from the world and getting something done," he says, "but physics doesn't work that way. Really great science requires not just smart people, great instruments, and hard work, but also friendships, relationships, and community. Glennys convinced the university to put a structure to something that emerged very naturally."

Far away from the sun-drenched offices on Washington Place, some CCPP faculty are at work on an experiment that will take place 100 meters below the ground at the European Organization for Nuclear Research, or CERN, which sits on the Swiss-French border near Geneva. With hundreds of scientists representing 20 member states, it is expected to replace the famed Fermilab as the world's leader in the business of "finding out what the universe is made of and how it works." CERN's premier project currently centers on the Large Hadron Collider, or LHC, a $6 billion particle accelerator located inside a 27-kilometer tunnel. The LHC collides protons at 10 million times per particle the energy of an atomic explosion, simulating the moments just after the Big Bang—the "birth" of the universe 13.7 billion years ago—and enabling scientists to study a model of its evolutionary process. Gia Dvali, NYU's Silver Professor of Physics, who spends about two-thirds of the year working at CERN, says that the experiment, which began this fall and continues through spring 2010, is something even Einstein couldn't have imagined. "This would have been considered science fiction 30, 40 years ago," Dvali says. "It's absolutely a dream."

COLLIDING PROTONS AT 10 MILLION TIMES THE ENERGY OF AN ATOMIC EXPLOSION, THE LHC "WOULD HAVE BEEN CONSIDERED SCIENCE FICTION 30, 40 YEARS AGO," GIA DVALI SAYS. "IT'S ABSOLUTELY A DREAM."

One unexpected bit of fanfare for the LHC came in the form of a global media crush last year when news outlets announced the possibility, according to some scientists, that the world could be swallowed by a

CCPP'S FACULTY, FROM LEFT: GLENNYS FARRAR, GREGORY GABADADZE, DAVID HOGG, ANDREW MACFADYEN, MASSIMO PORRATI, NEAL WEINER, MATTHEW KLEBAN, MICHAEL BLANTON, AND ROMAN SCOCCIMARRO. NOT PICTURED: GIA DVALI (SEE PAGE 36) AND ANDREI GRUZINOV.

PHOTOS: P. 30/31 © MAXIMILIEN BRICE/CERN; P. 32/33: STARDUST © RUSSELL CROMAN; PROFESSORS FROM LEFT 1, 2, 4, 5, 7, 9 © MATTHEW SEPTIMUS, 3 © DUSTIN LANG, 7 © GOGA VUKMIROVIC, 8 © JASON HOLLANDER; BOTTOM COURTESY OF DAVID W. HOGG, MICHAEL BLANTON, AND THE SDSS black hole born during the experiment. A week before the accelerator powered up for the very first time in September 2008, *Time* magazine reported that a German chemist had, unsuccessfully, filed an emergency injunction to stop the activation. For Gregory Gabadadze, associate professor and director of CCPP since 2008, who helped lay the theoretical groundwork relevant for this experiment at CERN, the hullabaloo was completely unfounded. The possibility of a catastrophic accident is, he estimates, "One over 10 to the many, many, many zeroes. It's so many zeroes that I don't even care."

IF DIMENSIONS ARE REVEALED BEYOND THE KNOWN FOUR—HEIGHT, WIDTH, DEPTH, AND TIME—IT WOULD OPEN A "PANDORA'S BOX" OF EXOTIC PHENOMENA.

Creating a micro black hole is, indeed, part of the aim of the project, which has been riddled with some early electrical and magnetic glitches that make some doubt it will ever reach its anticipated power level. But, if successful, it would send shockwaves through the physics community and would be much credited to work done at CCPP. It would effectively confirm the existence of extra dimensions (the known four are height, width, depth, and time) and explain several modern physics mysteries, including the dark components of energy and matter. Although the universe's expansion should be slowing due to a gravitational pull, it's actually increasing, which some scientists attribute to "dark energy," a force spread throughout the universe. Another element, called "dark matter," surrounds galaxies like our own Milky Way, and determines much of their properties. These two dark phenomena are so named because they radiate no light, but they demand attention, accounting for some 96 percent of the universe's total density.

The discovery of this dark realm in 1998 actually stimulated the ties between cosmology and particle physicists, because its implications could impact the known laws for both. A number of major theories surrounding these phenomena have been born or properly nurtured at NYU. In 2000, Dvali co-wrote, with Gabadadze and professor Massimo Porrati, a paper now known by their initials as "the DGP model"—an outline of gravity that laid the groundwork for many of the experiments in dark energy being conducted by NASA, and which has already been cited more than 1,000 times. Assistant professor Neal Weiner's research focuses on the possible relationship between neutrinos (small particles that travel near the speed of light) and dark energy, as well as theories of "electroweak symmetry breaking," which calls into question the foundation of particle physics laws and will be tested in the LHC. And a more thorough understanding of "supersymmetry"—the particle theory pioneered in part by former NYU professor Bruno Zumino and developed early on by Farrar—will also be explored in work there. "There's always a temptation among theorists to *not* make very specific predictions because then you won't get ruled out," Hogg notes. "People here are willing to put their name on the line. We're really unusual in that respect."

Observation is as crucial to understanding space today as it was in Galileo's time. In Argentina's Mendoza region, NYU is part of another huge effort, the Pierre Auger Collaboration, which includes some 200 physicists from 15 countries. At the Auger Observatory, scientists are examining ultra-high-energy cosmic rays and NYU, specifically, is using the results to test the validity of particle interactions. The speed of these rays is significant because, since they occur naturally, they dwarf those that may be achieved even by the LHC.

Back in North America, at the remote Apache Point Observatory near Roswell, New Mexico, a telescope scans space around the clock as part of the SDSS-III, the third installment of the Sloan Digital Sky Survey, a 20-institution collaborative project that started in 2000 and will continue through 2014. The latest effort will map in meticulous detail more than one-quarter of the visible sky and will process roughly 6.5 billion light-years worth of information. That's a lot of numbers, but for astronomer and NYU assistant professor Michael Blanton, who is data coordinator of the project, he's happy to sort through what most people can't even contemplate. "A lot of science happens by people doing rather mundane things very, very carefully, and making incremental progress," Blanton explains.

This "mundane" work will provide physicists the world over with theoretical tools for years to come. NYU is the primary data center for the survey, which in turn makes CCPP its intellectual home. The statistics are public information, and Blanton, along with CCPP's Andrei Gruzinov, Andrew MacFadyen, and Roman Scoccimarro, must anticipate how scientists may want to use them. As Hogg notes, "It's pretty hard to just give someone 750,000 galaxy positions and have them run with it." So NYU is charged with packaging the data for those like assistant professor Matthew Kleban, who works on new models in string theory, as well as those doing analysis at the LHC. It's a job perhaps only Blanton could make sound easy: "The fact is there's so much interesting stuff out there and we know so little about it that you can almost make these large maps and then just go fishing [for information]. And you're gonna find something interesting."

Because the light being viewed for SDSS-III has been traveling toward Earth for more than 6.5 billion years, astronomers are essentially watching a home movie playing backward halfway toward the birth of the universe. The closest points reveal recent cosmic activity, while the farthest points expose the workings of deep space as they occurred billions of years ago—allowing astronomers to "time travel" via projected images. Eventually, scientists hope to map back to the moments right after the Big Bang, when Blanton says estimates

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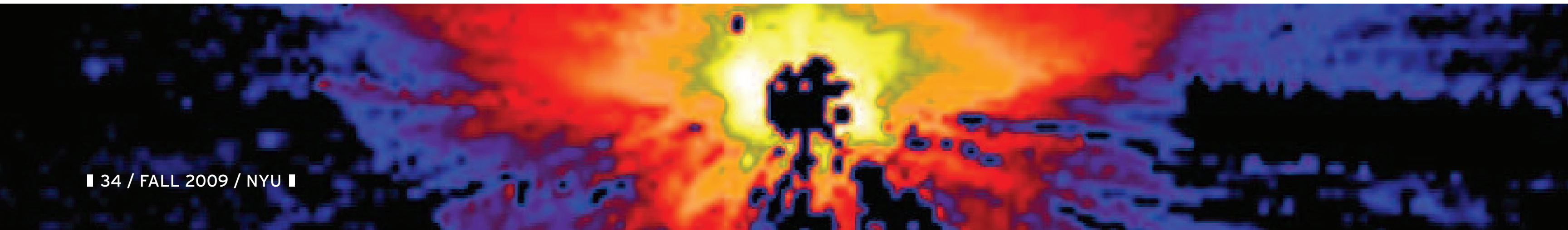


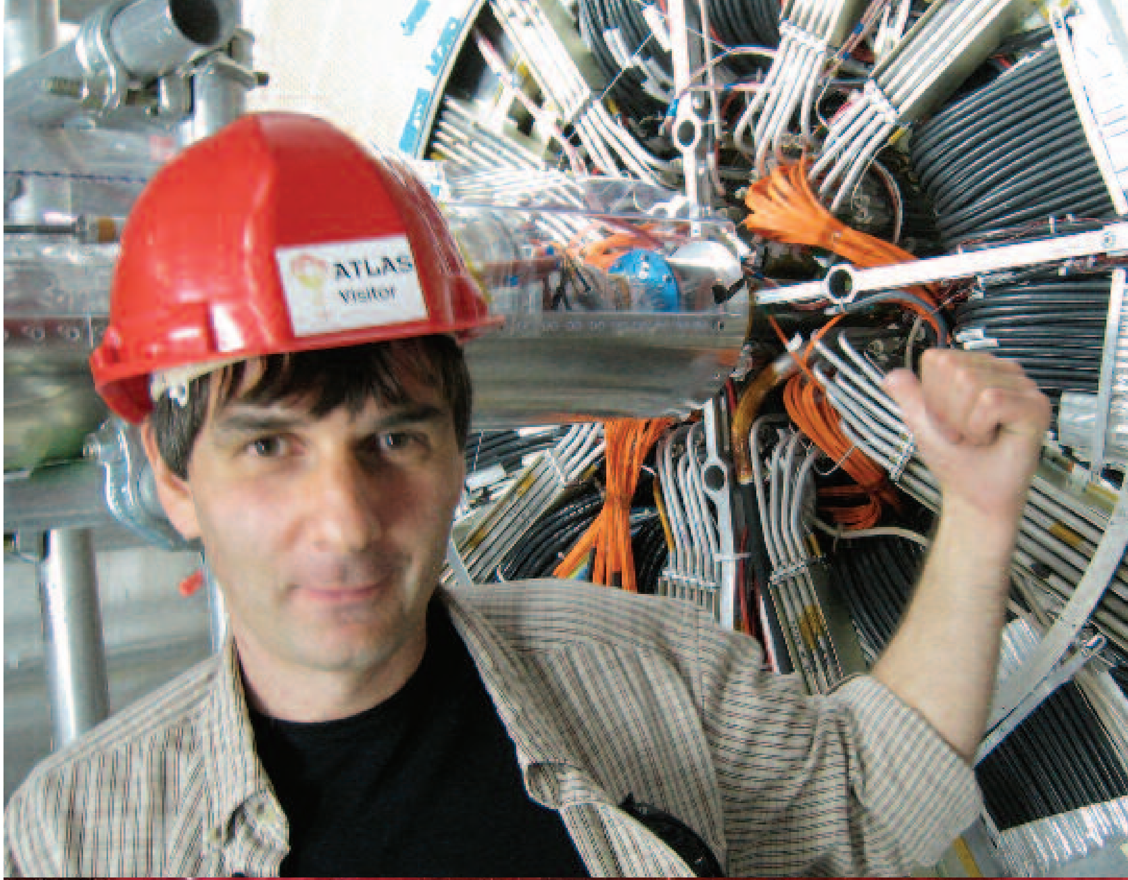
THIS NEW MEXICO-BASED TELESCOPE, USED AS PART OF THE SLOAN DIGITAL SKY SURVEY III, WILL HELP MAP IN METICULOUS DETAIL MORE THAN ONE-QUARTER OF THE VISIBLE SKY AND PRODUCE ROUGHLY 6.5 BILLION LIGHT-YEARS WORTH OF INFORMATION.

show that everything in our universe could have existed, literally, in a space the size of a thimble.

All this sky searching begs the inevitable question of what else astronomers may find—namely, signs of intelligent life elsewhere in the universe. Blanton believes "it's hard to imagine that there isn't" another form of life out there, noting that both Mars and Saturn's moon, Titan, are teeming with organic compounds. And it seems that we may not have to wait long for an answer. As telescopes soon expand to a projected 30 meters in diameter, Blanton thinks that the technology to detect life on exoplanets—those outside our solar system—should be available within 50 years. At that point, it's just a matter of zooming in on those places with characteristics similar to Earth's. "We know where to look," he says.

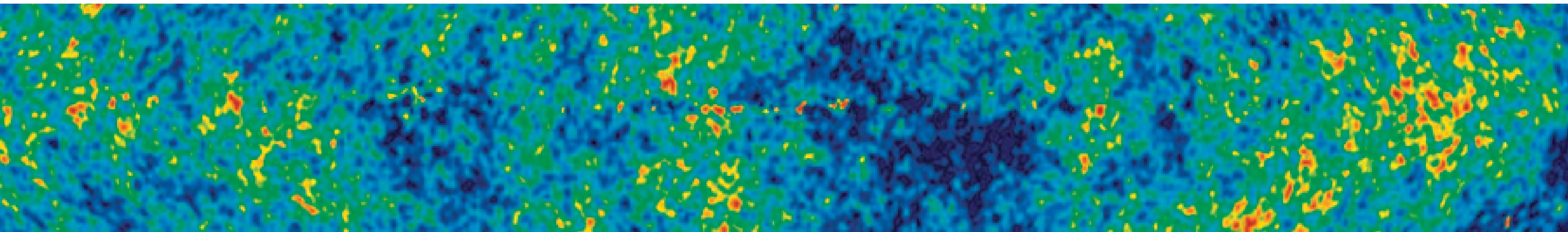
Whether alien contact is on the horizon or not, the 21st century is already proving to be one of the most revolutionary moments in the history of physics. There is a chance that news will emerge from CERN this spring that rivals the headlines of 1919, when a solar eclipse set the stage for Einstein's General Theory to be tested and proven. If extra dimensions are revealed, CCPP director Gabadadze says, it would open a "Pandora's box" of exotic phenomena for physicists to document and make sense of. But the experiments will prove win-win regardless of the outcome. In physics, as with all science, the goal is to advance knowledge; everything is a building block. As Gabadadze says, "Old theories aren't wrong, they just get embedded into a bigger and more precise one."

Most scientists agree that it's impossible to predict what value this next stage of progress will bring to the general public. After all, chemist Michael Faraday was uncertain how the electromagnetic field—which, for example, now helps charge your electric toothbrush and powers hybrid cars—might be used when he discovered it in the early 19th century. And CERN was the place where the first crude version of the World Wide Web was designed for the unglamorous means of helping physicists share data more easily. Some dream of a future full of radical technologies and Stanley Kubrick–inspired space travel, but scientists labor daily, heads down, because they know the work is more important than imagining the reward. Still, finding clues to our existence remains a pretty good motivator, and if the upcoming LHC experiments are successful, there will be a treasure trove. Whatever happens, one thing is sure, says Dvali from his office at CERN: "We're opening a new chapter."



PHOTOS: TOP © IRAKLI MINASHVILI; MIDDLE © STAR SHADOWS REMOTE OBSERVATORY; BOTTOM © NASA

TOP: GIA DVALI SPENDS TWO-THIRDS OF THE YEAR AT CERN, AND WILL ANALYZE DATA AS IT EMERGES FROM LHC TESTS. **BOTTOM:** USING AN ASTROMETRY ENGINE DEVELOPED AT NYU, SCIENTISTS CAN ANALYZE IMAGES LIKE "WISPS SURROUNDING THE HORSEHEAD NEBULA" TO DETERMINE THE SCALE OR ROTATION OF CELESTIAL BODIES.



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