# Forces

Jacobo Konigsberg

By Aaron Hoover

# of Nature

*UF professors lead two of the most ambitious, costly and potentially groundbreaking research initiatives in modern physics*

As a high school student in his native Mexico, one of Jacobo Konigsberg's favorite classes was philosophy. He loved the age-old mysteries surrounding the nature of matter, time and space at the heart of cosmology and metaphysics. David Reitze had a different obsession: astronomy. From his parents' home in Florida's Pompano Beach, he scoured the heavens with a series of ever-more-sophisticated homemade telescopes. His largest and best measured four feet in length, with a headlight-sized mirror and the zany appearance of a ray gun.

Konigsberg didn't become a philosopher, and Reitze is no astronomer. But both men, now professors of physics at the University of Florida, continue to pursue the basic questions at the heart of their teenage passions. The difference is that today they are each among the top leaders of two of the most ambitious, costly and potentially groundbreaking research initiatives in modern physics.

*Fermilab*


The stakes could hardly be higher. As the elected spokesperson for the Collider Detector at Fermilab, near Chicago, Konigsberg heads a team of 600 physicists from dozens of universities around the globe seeking to complete modern understanding of the underpinnings of the physical universe. Reitze, meanwhile, has the identical position at the Laser Interferometer Gravitational Wave Observatory Scientific Collaboration, based in Louisiana and Washington. His group of 570 scientists from 45 different institutions hopes to confirm the last major element of Einsten's theory of space and time by participating in a global effort to observe gravitational waves.

"We are both searching for something that people are sure exists — in our case, it's gravitational waves, and in Jacobo's case, it's the Higgs boson — but that no one has ever seen," Reitze says. "They are the last pieces of the puzzle."

## "The God Particle"

Physics circa 2007 is a bit like the globe during the era of the Great Explorers: The previously unknown is shrinking from the scale of oceans to islands, but new continents are also being discovered. Once unexplored territories in classical mechanics, electromagnetism and other areas have been filled in, but new phenomena such as dark matter and dark energy have emerged to take their place.

What's striking about the unanswered questions at the heart of Konigsberg's and Reitze's initiatives is that they are such vital missing links — and, at least in Konigsberg's case, ones capable of upsetting the entire mapped universe.

Nothing suggests this more colorfully than the nickname for the at-large particle that is the target of the work at the Collider Detector at Fermilab: "The God Particle."

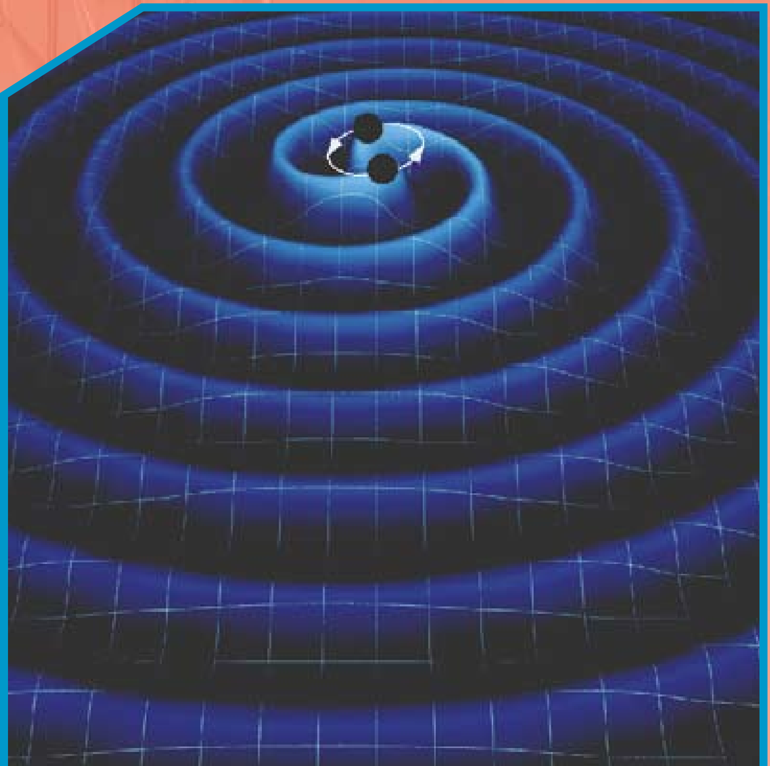
K. Thorne (Caltech), T. Carnahan (NASA GSFC)

At its smallest scale, matter consists of elementary particles that cannot be divided. Most people learned in school that these particles are atoms, composed of neutrons, protons and electrons. But this model is long out of date. Today's physicists have identified no fewer than 12 building blocks of nature, all of which fit into two basic types: quarks and leptons. According to the theory, known as the Standard Model, quarks and leptons interact by exchanging at least four different types of "force carriers," known as bosons.

Physicists have discovered most of these elementary building blocks through observations and experiments over the last 100 years. Some of this work occurred at the Collider Detector at Fermilab, located in Batavia, near Chicago. In perhaps the lab's biggest coup, CDF physicists announced in 1995 they had observed the top quark, the last of six quarks predicted by the Standard Model to be confirmed.

Konigsberg led one of the teams that made the discovery, which relied on data from the lab's particle accelerator known as the Tevatron — the largest particle accelerator operating today. "That was an amazing period for me as a scientist," he recalls.

But one essential ingredient to the Standard Model remains unverified by any experiment or observation: the Higgs boson. In the model, the Higgs plays the critical role of endowing particles with mass. Failure to find such a key particle could undermine that model, sending physicists back to the drawing board. "It's a very big prize," says Konigsberg. "It is, in a big way, the immediate Holy Grail."



## Catch A Wave

Gravitational waves have similar iconic status, although the stakes in their discovery are different.

Einstein's 1916 theory of general relativity equates the curvature of space and time with how matter and energy are distributed in the universe. The theory predicts that gravity can warp space, time and light. As a result, large or dense objects such as neutron stars or black holes will slow time, squeeze objects and bend light as they approach these objects' gravitational cores.

Most of the theory's predictions have been confirmed by observations and experiments. For example, by observing starlight near the Sun during an eclipse, scientists early last century confirmed the prediction that stars can bend light.

However, general relativity also predicts phenomena called gravitational waves — ripples in space-time thought to be caused by stars, black holes and other massive objects moving, spinning or orbiting each other. With two orbiting stars, Reitze says, a good analogy is two bowling balls spinning around each other on a rubber mat. The ripples pulsing through the rubber are the gravitational waves propagating into space.

The problem is that although physicists have found indirect evidence of gravitational waves, they have never observed the waves directly.

That's the point of the Laser Interferometer Gravitational Wave Observatory Scientific Collaboration, or LIGO, which Reitze heads.

"General relativity makes a lot of predictions that you can test experimentally, and we've completed most of those tests," Reitze says. "Direct detection of gravitational waves is really the odd man out — predicted for 90 years but yet to be seen."

But the importance of observing gravitational waves goes far beyond filling the last observational gap in Einstein's theory. Physicists could also learn much about black holes from gravitational waves. No telescope can see them, but the gravitational waves they emit could at least in theory paint a detailed picture. Physicists could also eventually use gravitational waves to observe and study events that cannot be "seen" any other way, including the Big Bang. That's because while there was no light for an estimated 380,000 years after the Big Bang, gravitational waves have existed from the start.

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"All of astronomy relies on light in one form or another," Reitze says. "Gravitational waves are fundamentally different."

## Quantum Dice

The overarching challenge for both the CDF and LIGO is detecting the Higgs boson and gravitational waves, respectively. And, with both experiments, UF physicists have contributed detectors or components widely regarded as key.

Like other accelerators, the Tevatron works by speeding up charged particles via electric fields. As the particles circle around the Tevatron's four-mile ring at close to the speed of light, they pick up energy with each revolution. Ultimately, protons and antiprotons, or matter and anti-matter, collide at an energy of two trillion electron volts and a rate of about 2 million collisions per second. The energy of the collision can then transform into new particles — mostly producing mundane results but, rarely, ultra exotic particles.

"When you have a head-on collision like that, you are essentially colliding these components of protons and antiprotons, and at that moment the basic laws of physics take over," Konigsberg says. "Essentially, somebody is throwing the quantum dice."

The challenge is to sort out the more compelling results from the far more common ones, especially because the latter can appear at first to be interesting and worth examining. Top quarks appear only once in the almost unimaginably large number of 10 to the tenth power collisions, which means scientists have a lot of sifting to do.

The CDF experiment is composed of several massive components aimed at maximizing the efficiency of this sifting process — including UF's cone-shaped detector, the Cherenkov Luminosity Counters.

Konigsberg said that this detector is essential to the Tevatron's operations because it measures the rate of proton and antiproton collisions. This measurement, notoriously difficult to make, is used to provide a frame of reference for any other collisions that occur.

As he put it, "We are keeping the tempo so that we will recognize the beautiful notes when they come, which is very infrequently."

Detecting gravitational waves is equally challenging.

LIGO physicists hope to observe a passing wave by measuring its ever-so-slight contracting and expanding impact on space. To return to the analogy of bowling balls on a rubber mat: What the physicists hope to do, in essence, is watch as a ruler placed on the mat shrinks or expands in response to a ripple. However, the effect of one gravitational wave on the length of the ruler — in LIGO's case, the "ruler" is the light storage arm on any of three laser interferometers — is exceedingly tiny.

LIGO's interferometers, located in Livingston, La., and Hanford, Wash., range from two to four kilometers in length and are placed at 90-degree angles to each other. In theory, a passing gravitational wave will stretch one arm and shorten the other. But the actual stretching and shortening expected to occur is beyond miniscule.

"We're measuring a change over our length scale equal to one ten-thousandth the diameter of a proton," Reitze says. "It's equivalent to measuring the distance from the Sun to the nearest star, 4.3 light years, accurately to less than the width of a human hair."

As with CDF, UF has contributed what Reitze called a "critical subsystem" to LIGO's detection apparatus: the input optics linking the interferometers and lasers. Reitze and other UF physicists spent several years designing and building the system before LIGO became operational in 2002. A team of UF physicists also contributed to UF's Cherenkov Luminosity Counters. Indeed, the UF LIGO and CDF groups are among the largest and most active in the physics department.

## Street Fighters

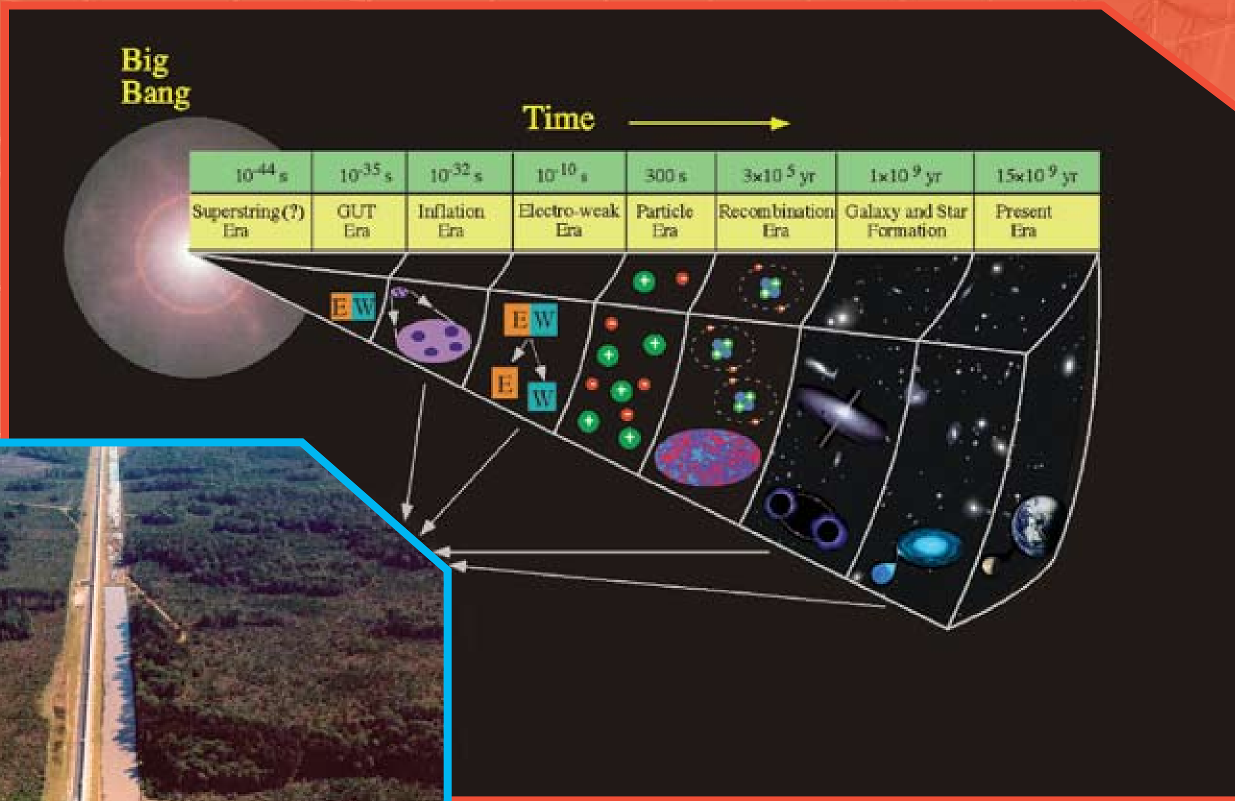
Both CDF and LIGO seek to observe very slight, very faint phenomena, so false positives are a constant threat. Earlier this summer, The New York Times ran a story on a rumor that CDF's competing team at Fermilab, the so-called D Zero team, had observed a "bump" in their data that could signal the Higgs. But there has not been an official announcement to that effect, and the race continues.

Meanwhile, Reitze says LIGO is so sensitive that any disturbance can have a dramatic effect. Researchers in Livingston can tell when, and at what speed, trucks pass over nearby cattle grates based on how they upset the observatory's lasers. LIGO researchers can also pick up earthquakes around the world, recording a quake every few hours, Reitze says. Indeed, the reason LIGO has detectors in Louisiana and Washington is to ensure that gravitational waves are recognized for what they are: If the Livingston detector picks up a signal not seen in Hanford, it can't be a gravitational wave, because a true wave would ruffle all the detectors equally and at nearly the same time.

Neither project has made a major discovery — yet Konigsberg and Reitze say that a non-observation is its own brand of success. For both initiatives, research so far has helped to narrow the search, or constrict the unknown territory where the Higgs and gravitational waves are expected to found.

"A big part of our program is to search broadly for new phenomena, and when we don't find it, we say those phenomena can't exist here," says Konigsberg. "In spite of not running into 'Holy Grails' yet, we have published hundreds of important results in particle physics coming from our experiment."

Konigsberg and Reitze each play an intimate role in the




NASA

*The LIGO Observatory in Louisiana (left) and Washington is the first step toward using gravitational waves to see back through 14 billion years of activity to the birth of the universe.*

science at CDF and LIGO.  But as spokesmen elected by their peers in 2006 and 2007, respectively, they also act as high-profile leaders and managers. Their responsibilities range from establishing research priorities to dealing with the press to representing the CDF and LIGO in reviews with funding agencies, a particularly important job. The $290 million LIGO is funded principally by the National Science Foundation, with the observatory ranking as that agency's single largest funded project. Fermilab is mainly funded through the U.S. Department of Energy's Office of Science, with NSF contributing a fraction to CDF.

Konigsberg and Reitze also have to appoint leaders to various parts of their operations and unstick thorny personnel matters.

"You have to deal with a very large set of principal investigators in their own groups and their own universities," Konigsberg says, "and sort of navigate through their own interests in putting the interest of the experiment first."

Reitze puts it more succinctly. "You have to be a street fighter. You have to be able to get the best results out of any situation."

Time is an issue for both projects. The CDF is slated to close in October 2009, a shut-down meant to coincide with the opening of the much larger and more powerful accelerator at the Large Hadron Collider near Geneva, Switzerland. Konigsberg's two-year term as spokesperson, meanwhile, ends next summer. As for LIGO, while the observatory currently ranks as the world's most sensitive gravitational wave detector, a highly competitive space-based detector, the NASA-sponsored Laser Interferometer Space Antenna, may be up and running sometime in the next decade.

It is far from clear that either experiment will capture its prize. But even if that doesn't occur, the journey will have been worth it, say Konigsberg and Reitze.

"The true work of science is unbelievably absorbing and can sometimes get rather political," Konigsberg says. "But the exciting and fundamental questions we are trying to answer always remain vivid in your psyche, and that keeps you going."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