

Physics in Cuba

Toni Feder

Passion and creativity drive physics despite difficult circumstances.



SCULPTURE OF DON QUIXOTE
in the Vedado section of Havana.



Think of science like art, says Aurora Pérez Martínez. “It’s an important part of culture, like opera, like ballet.” A theoretical physicist at the Institute of Cybernetics, Mathematics, and Physics (ICIMAF) in Havana, Pérez is worried that nowadays science, in contrast to the arts, is not adequately valued in Cuba. “Authorities ask why we are working on something if it’s not applied. They want neutrinos on a plate. But ballet doesn’t need applications.” Cuba has tremendous human capital, she continues, “but the country is spoiling. People leave for better opportunities.”

Education in Cuba is excellent. A 2006 UNESCO study of third- and sixth-grade students in the Caribbean and Latin America found that Cuban children were the region’s most accomplished in math and science. Cuban physics students easily gain admission to undergraduate and graduate programs abroad. But for scientists who want to remain in Cuba, maintaining a research program is tough. On top of the struggles in daily life—inadequate pay, power outages, poor transportation, shortages of basics from toothpaste to pens and paper—they have to contend with a lack of funding and equipment, lousy internet connections, strained political relations between Cuba and the US, and a host of associated problems. (For an earlier survey of physics in Cuba, see the feature article by Angelo Baracca, Víctor Fajer, and Carlos Rodríguez, *PHYSICS TODAY*, September 2006, page 42.)

Despite the difficulties, a dedicated cadre of physicists perseveres. The Cuban Society of Physics has 410 members, of which about half are at universities and research institutions, and the rest are high school teachers. Isolation can lead to people working on outdated topics, but some manage to stay at the frontiers. Among the fields that Cuban physicists are strong in are condensed-matter theory, quantum field theory, astrophysics, and complex systems. They are also strong in the government’s priorities of biotechnology and medicine.

When President Barack Obama took steps toward thawing relations with Cuba in December 2014, Cuban scientists hoped that traveling, obtaining equipment, collaborating, and the like would become easier. But in November 2017, President Trump reimposed business and travel restrictions that had been eased. Among scientists living in Cuba, the attitude tends to be that they can endure whatever comes. Willpower is our main strength, says María Sánchez Colina, a physicist at the

University of Havana and president of the Cuban Society of Physics. “In spite of all the difficulties, people find ways to do their research—most of all, by being very creative.”

Shifting history

Before the Cuban Revolution prevailed in 1959, universities emphasized teaching over research. The new government under Fidel Castro recognized the need to build up the country’s science and engineering capacity, says Carlos Trallero, one of the country’s best-known theoretical physi-

cists. “The key point was to create a faculty of science to help develop the country. Everybody wanted to work in one direction that could help.”

In the early years of the revolution, scientists from many countries went to Cuba to help modernize university education and implement research structures. By the 1970s and 1980s, visitors were mostly from the Soviet Union and other Eastern bloc countries. And for about three decades, until the collapse of the Soviet Union in 1991, Cuban scientists routinely did at least part of their studies in the Eastern bloc. Cuban physicists were educated by Soviet teachers at a time when Soviet science was top-notch, says Federico García Moliner, a Spanish physicist who maintains long-standing, close connections with Cuban colleagues. “Their mathematical basis is something I have always envied.”

Once they returned to Cuba, the Eastern European-educated scientists took on positions of responsibility. Before completing their PhDs—sometimes even before finishing their undergraduate degrees—they led research groups, formed scientific institutions, and taught undergraduate courses. “We had a critical mass, and we made a second revolution—in physics,” says José Marín Antuña, an emeritus physicist at the University of Havana. Marín went to Moscow State University in 1961. He returned to Cuba in 1967 with a master’s degree in hydrodynamics. Just a week later, he says, he began teaching physics to undergraduates. A year later he was head of theoretical physics at the university. Marín returned to Moscow to defend his PhD in 1986.

With the collapse of the Soviet Union, Cuba lost its principal market for sugar and oil exports. The economy crashed. The impact of the US embargo, which had been in effect since the Cuban Missile Crisis in 1962, strengthened. Research, along

with everything else, stagnated. “Cuba became a very complicated place to live,” says Alejandro Bordelois Cayamo, an engineer who earned his master’s degree in Leningrad in 1981. He returned to the University of Santiago de Cuba on the eastern end of the island, where he earned his PhD in 1999. The 1990s, he says, were “a very dark decade for the Cuban people.”

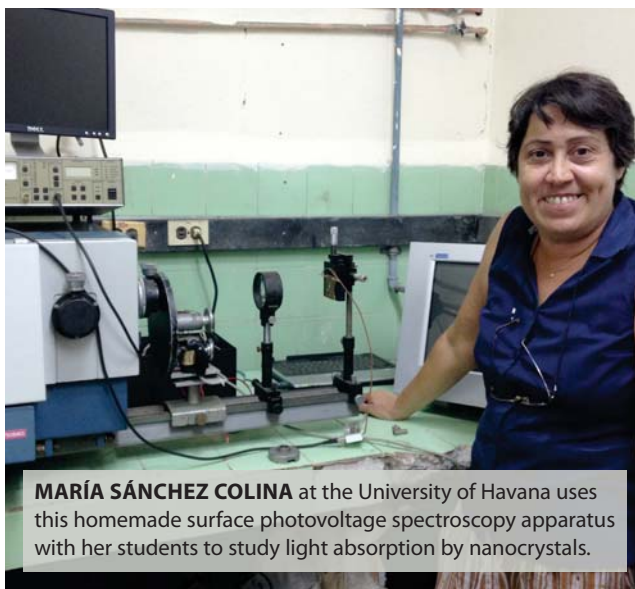
Cuban physicists turned their sights to Latin America and Europe for collaborations. Relationships with those regions are also affected by geopolitics. Sánchez recalls that ties to Europe weakened in the early 2000s due to pressure from the US to adhere to its embargo. Laws in Europe didn’t change, but behavior did. “Scholarships to go to Europe became scarcer and cooperation decreased dramatically,” she says. “After Obama relaxed the US stance toward Cuba, Europe also relaxed.” The scholarships returned. Physics in Cuba continues to depend on relationships with scientists around the world. Since the end of the Cold War, the institution that has had by far the greatest effect on Cuban physics has been the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy, says Roberto Mulet, a theoretical physicist at the University of Havana.

Universities and research centers

Cuba’s largest physics faculty is at the University of Havana. Founded in 1728, the university is the country’s flagship campus and a source of national pride. It has about 60 faculty members in physics, including a dozen or so who are still working on their PhDs. Some 50 students a year matriculate as physics majors. Typically, about a quarter graduate, says Mulet, who until last July was the faculty’s vice dean for research activities.

Another roughly 15 students graduate each year in physics from the Higher Institute of Technologies and Applied Sciences, which was founded in the early 1980s by Castro’s eldest son, Fidel Castro Díaz-Balart. Last year it became part of the University of Havana, but it remains a stand-alone institute. It offers courses in nuclear engineering and energetics, radiochemistry, nuclear physics, and meteorology. It has 90 faculty members—70 in nuclear physics and engineering—and about 230 undergraduate students.

In the past 20 years, says Sánchez, 80 physics graduates have left the country to pursue their master’s or PhD studies. About half went to countries in Latin America, and the others



MARÍA SÁNCHEZ COLINA at the University of Havana uses this homemade surface photovoltage spectroscopy apparatus with her students to study light absorption by nanocrystals.

were split among Canada, Europe, and the US. “Almost none have returned.” That’s true for the University of Havana, but it’s similar elsewhere, she says. And the trend continues. “I don’t have statistics, but because of the bad economic situation, a big part of young researchers leave to pursue their research and don’t come back.” That outflow leads to problems with teaching and running undergraduate and graduate programs in Cuba, she adds. Returning to Cuba has been difficult for emigrants, but it is easing now that the Cuban government is allowing people to reestablish residency in the country.

In fall 2016, members of the University of Havana’s physics faculty moved back into their building from the scattered lab and office spaces they’d occupied during a decade of renovations. Offices and classrooms are spacious and in good condition, but more than half of the building, including most laboratory space, is still being fixed. And the department lacks funding for such basics as laboratory supplies and journal subscriptions. As at other institutions across the country, it’s the norm for faculty members’ desks to be located in an undergraduate laboratory or other shared space.

ICIMAF in Havana has 30 permanent researchers in math, physics, and computer science. Its theoretical-physics department was founded in the 1970s and has about 8 researchers and another 10 or so students. In the past 20 years, the theorists have published some 200 papers in international peer-reviewed journals. Pérez studies neutron and quark stars and related topics. Others do research in quantum field theory, general relativity, astroparticle and high-energy physics, cosmology, and condensed-matter physics. The four physicists and four engineers who make up ICIMAF’s applied-physics group focus on ultrasound and piezoelectric ceramics. Like many others around the country, the group has shrunk, says Pérez, as members moved abroad. Across town, the Center for Technological Applications and Nuclear Development has 34 scientists, whose areas of research include optics and nuclear applications in agriculture, the environment, health, and energy.

Cuba has two other main academic centers for physics. One is the University of Santiago de Cuba, which is 900 km east of Havana and is known colloquially as Oriente. The other is the



ARBELIO PENTÓN MADRIGAL (left) and Roberto Mulet are physics professors at the University of Havana.

Central University “Marta Abreu” of Las Villas, which is 260 km east of Havana in Santa Clara. Oriente’s physics faculty has about 30 members, whose research emphases lie in medical and biophysics, solar energy, and seismology. Las Villas has about two dozen physics faculty, who work mostly in planetary sciences, cosmology, material sciences, and medical physics. The Las Villas department currently confers only undergraduate degrees, but it is planning to relaunch a doctoral program in math and physics this year.

In total, Cuba has about 40 universities and 200 science and engineering centers. The centers span the range of R&D from basic research through to the commercialization of products. For example, the National Center for Scientific Research (CNIC) in Havana conducts research and develops products and services in biotechnology. In general, centers—especially those like CNIC that focus on national priorities—have better equipment and better pay, and researchers sometimes have funds to attend international conferences.

Top science, bottom resources

Sketchy internet access is a major problem. Cuba’s only fiber-optic cable connection is with Venezuela. More cables haven’t been laid because of the US blockade, says Sánchez. The internet is too slow to browse or to download large files. Often the best way to obtain a copy of a research paper is to request it via email from colleagues abroad or from the ICTP. “I get papers within a day,” says Alejandro Cabo, a theoretical physicist at ICIMAF. That tactic works for papers you know about, but it’s not a good way to stay current with literature. And websites are sometimes seemingly arbitrarily blocked.

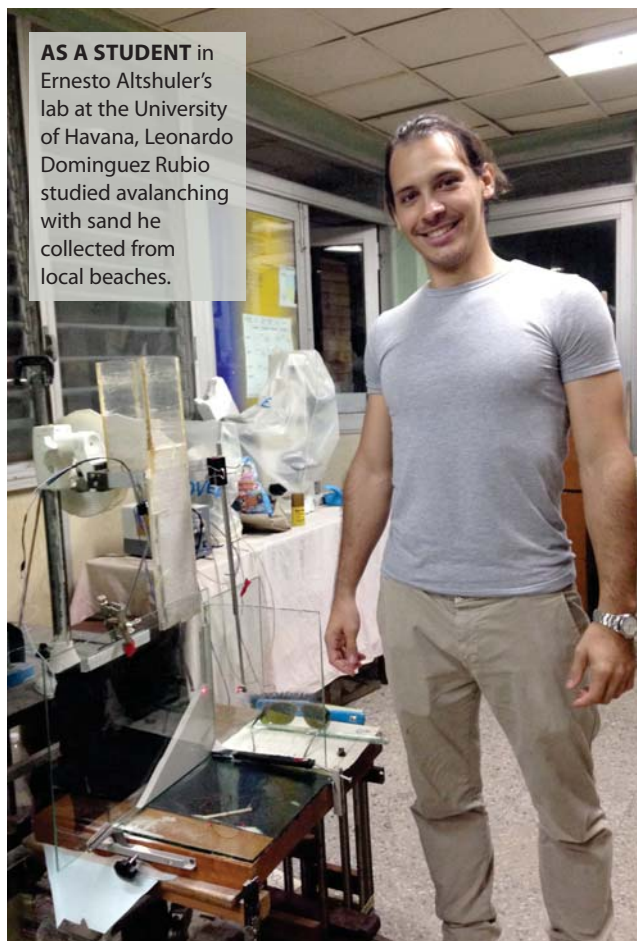
Owen Fernández Piedra is a theoretical physicist who specializes in supergravity, black holes, and quantum field theory in curved spacetimes. The lone researcher in physics at the University of Cienfuegos in central Cuba, he notes the frustration of restricted, rationed internet. When the weekly quota is exhausted, “we no longer have access,” he says. “Looking for information, exchanging with colleagues from other parts of the world, accessing webpages, downloading articles and books of some megabytes, and uploading papers for publication in physics journals is a challenge.”

Another consequence of poor internet and the lack of access to certain websites is that Skype and other video conferencing software do not work in Cuba. Professors, scientists, and medical doctors get about 40 hours a month of home internet access, but the connection is typically via phone line and is slow and intermittent.

Cuba has no synchrotrons, research reactors, or other large-scale user facilities. To conduct structural studies with x rays or neutrons or to use big instruments, scientists must go abroad. A few Cuban physicists participate in experiments at CERN. Typically, though, conditions push physicists toward either theory or tabletop experiments. “We try to do top science with bottom resources,” says Carlos Cabal Mirabal, whose research area is NMR spectroscopy. “It’s not an easy task.”

The Institute of Materials Science and Technology at the University of Havana opened in 1985 and hosts shared instruments for making and characterizing materials. It is home to the country’s first atomic force microscope, which was built by University of Havana physicists. Recently the ministry of higher education furnished the lab with new equipment, in-

AS A STUDENT in Ernesto Altshuler’s lab at the University of Havana, Leonardo Dominguez Rubio studied avalanching with sand he collected from local beaches.



cluding a high-performance liquid chromatograph, an electron scanning microscope, and three kinds of spectrometer: x-ray fluorescence, UV-visible, and atomic absorption. “It’s a good sign,” says Sánchez, “but it’s not enough.” The new equipment is more useful for chemistry than for physics, she adds. And although the facility is meant to serve scientists from across Cuba, financial difficulties and poor transportation make it *de facto* accessible to locals only. “People from Oriente can’t come,” she says. With stipends available from abroad, “it’s probably easier to go to Europe.”

In addition to building their own equipment, experimental physicists nurse decades-old Soviet instruments to keep them functional. They also have items that were donated by institutions and individual scientists abroad. “I have brought equipment for research and teaching from Spain and Mexico,” says Sánchez. “In Madrid, they give me [work]stations for our electronics lab. I flew back with six of them. One time I brought vacuum pumps.” Sometimes scientists get around the US embargo. Says the University of Havana’s Mulet, “We have magicians and bribes. We make money travel further. But buying new equipment through an intermediary doubles the price.”

Says Sánchez, “I used to be an experimentalist, but I switched to modeling and simulation as they are much cheaper to carry out.” She studies the thermal behavior of semiconductor devices, for which excess heat generation is a big challenge. These days, she is getting back into experiments. Her group is developing a system to do surface photovoltage spectroscopy. With a price tag in the tens of thousands of dollars, a commercial

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instrument is out of reach. “We use a spectrometer inherited from the period of collaboration with the former Soviet Union and elements of modern electronics to implement our own system with a relatively low cost,” she says.

Down the hall, Ernesto Altshuler and his students study superconductivity, ant communication, and granular materials. They build their own experiments using scavenged computer parts, Styrofoam pellets, items made with a 3D printer by a former student who is now in France, superconducting tape provided by US collaborators, and local ants and sand. They study the source of in-plane anisotropy in high-temperature superconducting tapes, the effects of Mars’s gravity on the performance of a rover wheel, how objects penetrate granular matter, and how and whether ants can communicate information through a barrier they can’t cross. “We ask questions that we can make progress on,” says Altshuler.

At the applied branch of ICIMAF in Havana, Eduardo Moreno builds large ultrasound guides for nondestructible testing of pipes for the oil industry. The work grew out of his PhD studies in Poland, and it continued as a joint project until the dissolution of the Soviet Union. “The collaboration disappeared as a consequence of history,” says Moreno. He continues to work on ultrasound for oil pipe diagnostics. With colleagues from Spain and Latin America, he has formed a network of scientists who develop ultrasound techniques for medical uses.

By the late 1980s, the lack of medical equipment in hospitals had become a critical problem in Cuba. “It was very important to improve MRI diagnostic possibilities in our hospitals,” says Cabal, who at the time was dean of physics and mathematics and head of the magnetic resonance lab at Oriente. Under his direction, a team designed and built several MRI scanners. The project, he says, “began as a consequence of the US blockade.” It was impossible to buy an MRI machine, he explains, because even when the companies that produced them were in Germany or Japan, they had US components in excess of the allowable limit of 10%.

The University of Santiago de Cuba’s Bordelois worked on the MRI project back in the 1980s. As an RF engineer who had graduated in the Soviet Union, he was assigned the task of designing and constructing a system for generating high-intensity pulsed magnetic fields. The whole-body magnet was largely produced at an iron foundry, and parts of the coils were made at the workshop of a cane sugar mill, he recalls. Then, as now, computers in Cuba were weak, so the team built an external pulse programmer with one computer to control the hardware and installed another to process data and reconstruct images. The completed machine was installed in a hospital in Santiago de Cuba.

The team members went on to build smaller, more sophisticated MRI machines. They continue to develop magnetic resonance instruments for studying sickle-cell anemia, which afflicts about 4% of Cubans. Bordelois says he considers the building and implementation of the MRI machines “the most important [achievement] for the technical sciences in Cuba in the last three decades.”

Based on the MRI project and on his teaching and research experience, Cabal was asked by Fidel Castro in 2005 to join a team that would set up 35 high-tech medical centers in Venezuela. The centers were equipped with MRI scanners, 3D



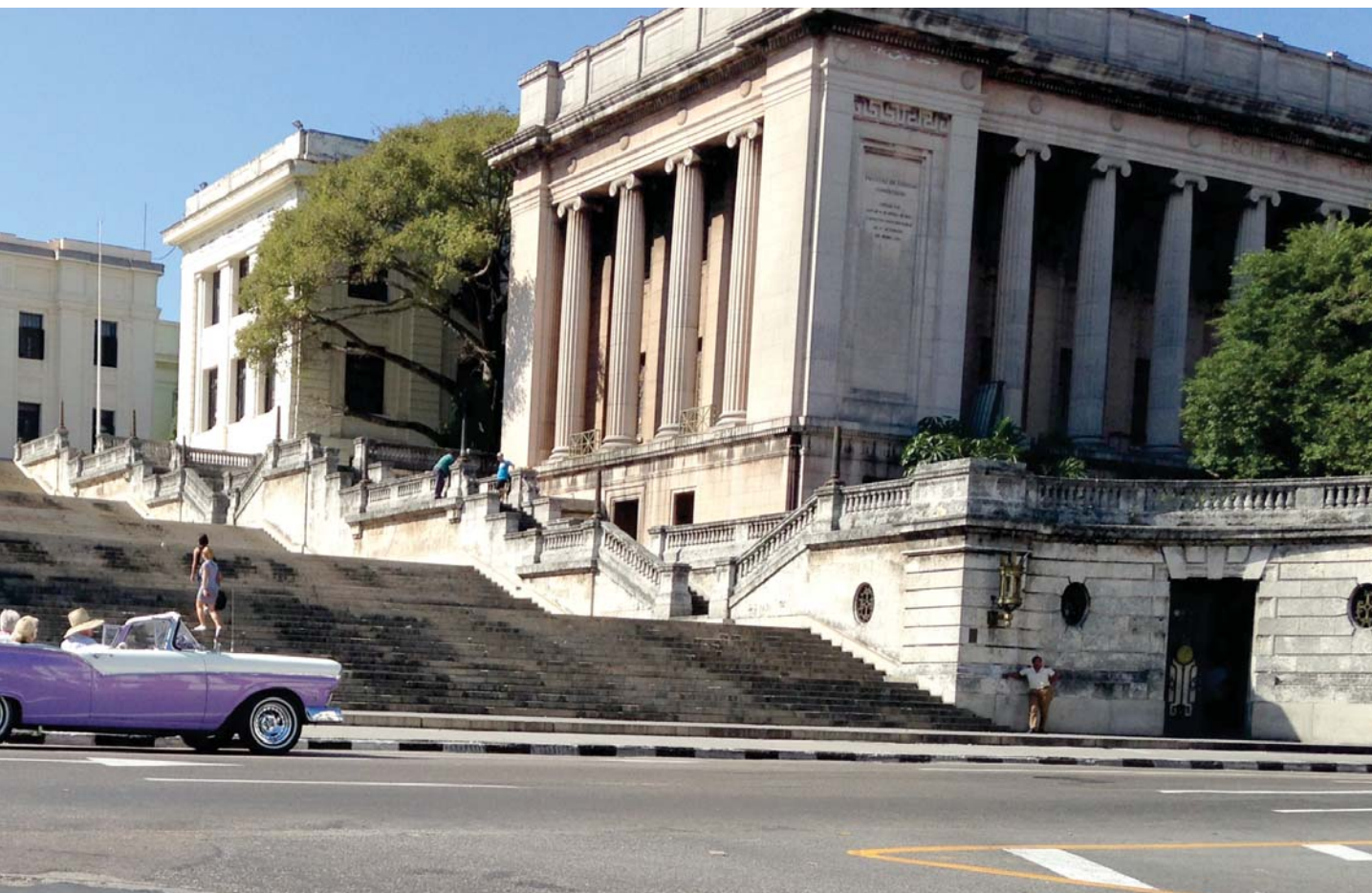
ultrasound, CT scanners, mammography units, and electrocardiographs and other diagnostic instruments. In exchange for designing the centers and training technicians, Venezuela provided money for Cuba to set up similar centers at home, recalls Cabal. After three years he settled in Havana, where today he is a researcher at the Center for Genetic Engineering and Biotechnology.

What about the next generation?

University faculty earn about 40 Cuban convertible pesos (CUC), or \$40, per month. Researchers at government centers take home up to twice that. For comparison, a tourist can rent a room in someone’s home for 30 CUC per night, and a local cab ride might be 5 CUC. “A waiter or dishwasher working in a private [nongovernment] restaurant gets paid more than we physicists do,” says Altshuler. Faculty members, like other citizens, get some rations—oil, rice, and coffee, for example—plus subsidies for such things as medicine, education, and transportation.

A common way for academics to make ends meet is to regularly spend a few weeks or months abroad. To do so, they have to be invited and subsidized—their salaries don’t cover living costs, let alone airfare. For example, Altshuler goes to France and the US, and Cabal has recently worked in Argentina, Germany, Italy, and Russia. Many scientists have close ties with scientists in Mexico. Some get invited to the ICTP.

The time abroad is invaluable both financially and professionally. Since 2005 Sánchez has been going annually to Madrid to teach and conduct experiments, sometimes bringing samples with her. “It’s a lifeline,” she says. “Not just for me and my group. My colleagues give me samples too. This is common



practice." At home, she says, "we have almost nothing for characterizing samples—nothing in photoluminescence or Raman spectroscopy." During her eight weeks in Spain this past fall, she says, "I was crazy doing experiments." The data are key, she says, and so are the intellectual exchange and the money. During their stays abroad, Cuban scientists receive stipends or, in the case of teaching, salaries. "We live because we save money from this type of activity," says Sánchez.

Lining up all-expenses-paid invitations year after year is a challenge. Researchers keep an eye out for funding opportunities, meet people at conferences, write emails to physicists working in related areas of research, and generally seek and nurture professional relationships. Still, the lack of local funding limits scientific exchange, notes Cabo, who has collaborators in many countries.

Fernández of the University of Cienfuegos has spent time in Brazil and Mexico. When he goes abroad, he lives as economically as he can so that he can afford to buy clothes and shoes and to maintain and furnish his house when he returns. Fernández, who last year was recognized with an award by the Academy of Sciences of Cuba, also does odd jobs to earn extra money. "I have worked as a painter, a bricklayer, a carpenter's assistant, a physics tutor. Anything that gives me some money to live on," he says. "These jobs tend to be exhausting and time consuming, so I lack time to work on my research projects."

Other physicists also report supplementing their incomes—they drive cabs, translate, rent rooms, receive money from relatives who live abroad, and do consulting work. For example, Moreno does consulting gigs in Europe every year or so, usually related to inspecting oil pipes with guided sound waves or his expertise in finite element analysis. Cubans bid lower

than Europeans on such jobs, he says. "In Spain, they are happy to pay me €80 [about \$95] an hour," he says. "I get hired rather than someone from Germany."

It's also common for Cubans to go abroad for graduate studies, again both for financial reasons and to participate in the international physics enterprise—with the modern equipment, know-how, and networking that entails. The ICTP, which focuses on developing countries, hosts about 15 visitors a year from Cuba, says director Fernando Quevedo. And every year or so it accepts a Cuban student into its graduate programs. The physicists from Cuba are among the best prepared of those going to the ICTP, Quevedo says. More broadly, the ICTP spends about €200 000 a year to subsidize Cuban visitors to the ICTP and activities in Cuba. "We support students at ICIMAF, help with conferences, and so on," he says. "For them, it can be the difference between doing physics or not."

Another path to studying abroad is the "sandwich PhD," in which students split their time between institutions in Cuba and abroad. The arrangements can be customized for individual students, says Mulet. "We want to be flexible, and for people to spend time here too. Otherwise we lose them completely." The relationship is one of hate and love, he adds. "The scientists outside of Cuba want to help, but they take away our good students. If students spend four years abroad, they don't come back. If they do a sandwich PhD, they may come back to Cuba."

Sandwich programs are not currently possible with the US. Over the years, however, a trickle of Cubans have come to the US to get their PhDs. Carlos Alberto Trallero, son of the theoretical physicist Carlos Trallero, is one. He went into physics, he recalls, because when he was growing up and the Soviet Union had yet to collapse, "education was at the top of the

pyramid. You could have an impact on society. And my dad had a Russian car."

As an undergraduate, Trallero presented at a conference in Brazil. A physicist from Stony Brook University spotted his work and invited him to apply to graduate school there. "It was almost impossible," says Trallero. For one thing, he couldn't take either the Graduate Record Exam or TOEFL in Cuba. In the end, the university waived the fees and exams, and he went there in 2002.

Trallero found he was better prepared than his US-trained classmates. He had done theory until he went to the US. But once he had arrived, he decided to give experimental physics a try. "In terms of education, in terms of raw intellect, Cuba is a good place," he says. "But it's hard to work there. The internet is bad, there are not sufficient resources. It is still isolated." Trallero is now on the faculty of the University of Connecticut in Storrs.

Mulet and others readily admit that one can do science more easily in many other countries. But the scientists who stay in Cuba have strong attachments and want to contribute to their country. "Everybody has thought of leaving," says Mulet. "My decision to stay is based on a commitment to the history of the country and to other people. If we all leave, then what about the next generation?"

SOS

Cuba invests about 0.5% of its gross national product in research, according to Castro Díaz-Balart, a nuclear physicist who at the time of his suicide on 1 February was the government science adviser. That allocation puts Cuba ahead of most of Latin America and in line with the poorest European countries. During recent decades, he wrote in recent emails to PHYSICS TODAY, Cuba has graduated a critical mass of engineers, technicians, researchers, and professors, "who are the pillars and the most valuable asset of the country's scientific system." He pointed to bionanotechnology and how it supports the pharmaceutical industry as among the country's strengths. Cuba produces vaccines and more than 700 drugs—enough to meet about three-quarters of the country's needs. Examples of drugs developed in Cuba include Heberprot-P to treat diabetic foot ulcers, Nimotuzumab for brain cancer, and monoclonal antibodies as anticancer vaccines.

But Castro Díaz-Balart noted that stronger ties between research and industry are needed. He cited a recent analysis by the country's Academy of Sciences that found that economic problems and the pressures of the US embargo are resulting in "a weakening of the scientific potential" of the country. He also pointed to some official collaboration between Cuba and the US. Agreements to work together in the areas of meteorology, seismology, and wildlife protection were signed in 2015 and 2016.

"It's significant that Cuba and NOAA signed the agreements after 54 years of hostility between the countries," says Fernando Bretos, a marine biologist in Florida. Since 1999, he has been working with Cuban scientists to monitor sea turtles,

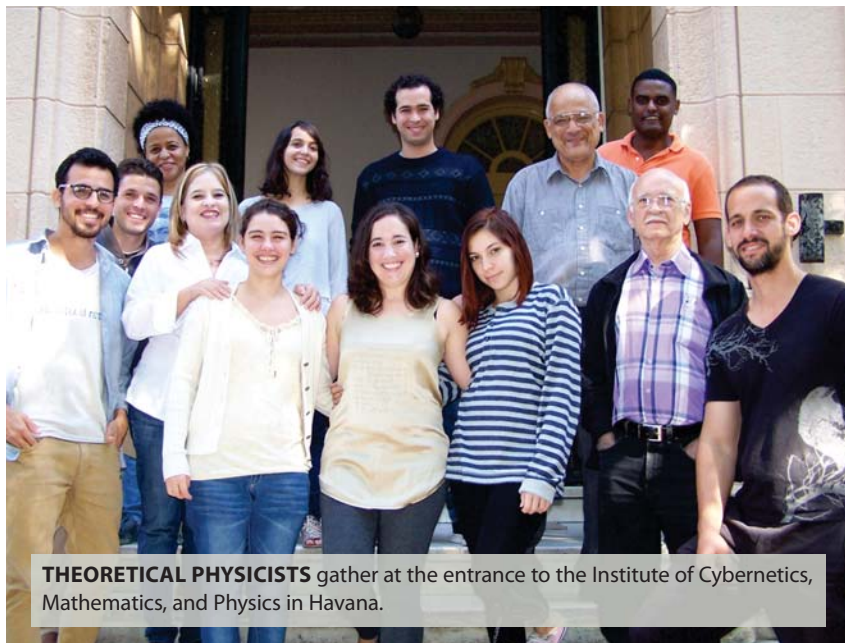
corals, and other marine life. The marine environments of the Caribbean Sea and the Gulf of Mexico face the same threats—tourism, hurricanes, oil spills, and sea-level rise. "So it makes sense to monitor in the same way and to share data," he says. Longer-term goals entail training people and sharing equipment. But since the signing, he says, "not much has happened. There is no money. Things have fizzled a bit." Still, collaborations continue on the ground.

At the nongovernmental level, exchanges occur between the US and Cuba both quietly and with fanfare. This year, for the third time running, leaders of the American Physical Society (APS) will participate in the Cuban Society of Physics's annual meeting. Since 2012 APS has made its online journals freely available to the Cuban physics community. And 2017 was a good year for US–Cuba physics relations, says Pérez. Among other interactions, she notes that she visited Fermilab and the City University of New York. Cabo attended the APS March meeting in New Orleans (in earlier attempts by him and others, visas often came through too late). This past August, Sánchez accompanied 14 Cuban students to Washington, DC, for an American, Canadian, and Mexican graduate student physics conference.

Before Trump took office, Cuban physicists were optimistic about normalizing ties with their US colleagues. They anticipated access to user facilities, easier entry to attend conferences, student exchanges, better availability of equipment and journals, and the like. Those hopes are now on hold.

But what Cuban physicists say they need above all is a pay raise. In the 1980s, says Sánchez, "you could live here on your salary. Not fancy, but with dignity." Her daughter, also a physicist, lives in France. "She sees that I, head of the Cuban Society of Physics and former chair of the University of Havana's physics faculty, can't even afford a car!" At press time, the Cuban Society of Physics leaders were drafting an SOS letter, which they planned to send in February to the president and the minister of higher education.

Despite all the hardships and challenges, Pérez declares, "We are here and we are producing physics and training physicists!"



MONICA ROJAS VIDAURETA