# Si science impact™

A special report on physics in Brazil

Annual review 2013

# New horizons for Brazilian science

## Open facilities drive research success

## Collaboration: Brazil takes global view

## The rise of experimental physics

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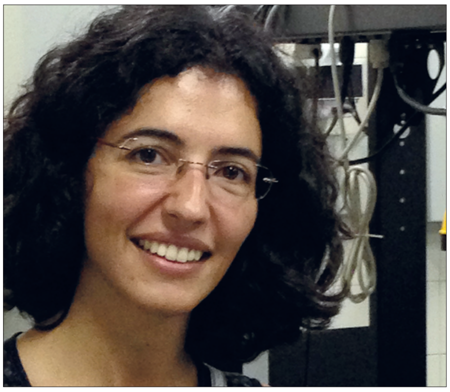
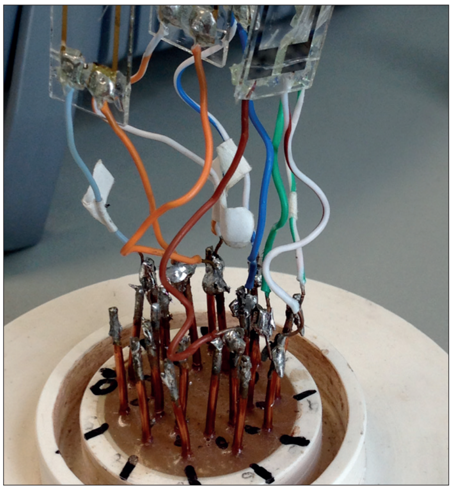


**Optics star** Katiùscia Cassemiro is one of a number of young experimental scientists working in quantum information, **p10**



**Tingling tastebuds** An electronic tongue allows efficient quality control of agricultural products such as wine and coffee, **p12**

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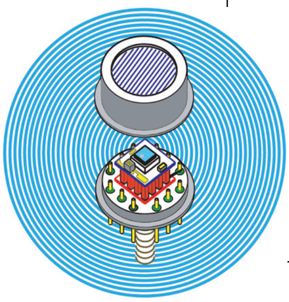

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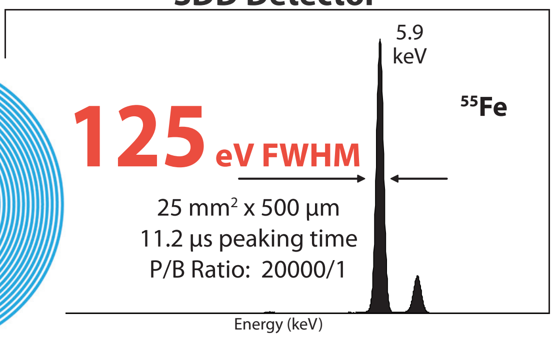


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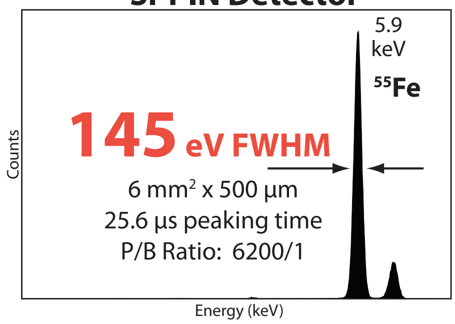


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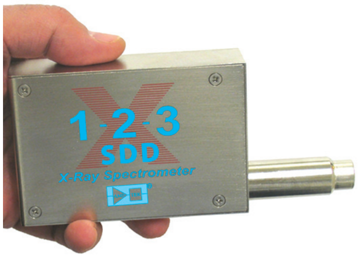
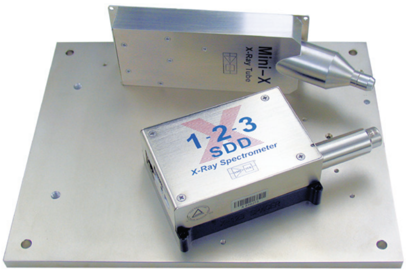



### XRF Experimenter's Kit

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PHYSICS IN BRAZIL

# New science, new horizons

*Rapid increases in science funding are transforming Brazil's research landscape, as Susan Curtis reports from some of the country's leading physics institutes*

Isaac Newton summed up the spirit of scientific endeavour when he wrote that his pioneering work on optics was merely the result of "standing on the shoulders of giants". Newton was fortunate to live in a country where there were plenty of scientific visionaries to inspire him, but until recently most physicists in Brazil had to look far beyond their borders to find the role models who would shape their research careers.

"Many people don't realize just how young science is in Brazil," says Celso Pinto de Melo, the current president of the Brazilian Physical Society (SBF) and a professor of physics at the Federal University of Pernambuco (UFPE) in Recife. "The first modern university, the University of São Paulo, was established in 1934, and the first graduate programmes in physics didn't emerge until the 1960s."

That can be hard to believe when walking around the vast campuses of Brazil's leading research institutions, which are now home to thousands of researchers and students. Indeed, Brazil has catapulted its science investment from \$6.6 bn in 2000 to \$25 bn in 2010, and over the same period its scientific output has more than tripled. "We have made remarkable progress over the last 30 years," says Melo. "But we still have a lot of catch-up to do."

**Order and progress** Brazil hopes that greater investment in scientific research will deliver economic progress.

## Back to the future

Melo explains that formal funding for university research didn't begin until 1951, when two federal agencies were created: CNPq, the national research council; and CAPES, which is connected to the ministry of education. Even then, most of the money was linked to individuals rather than projects. "The two federal agencies had the mission of providing fellowships to the best students and researchers," says Melo. "The attitude in government then was that science is expensive and there's no need to invest, so instead individual researchers were given grants to work at leading overseas institutions."

**"Physics has become more important. We are making good progress"**

It wasn't until the 1960s and 1970s that Brazil started to develop its domestic science base. One key turning point was the state of São Paulo's decision to set up its own research foundation, FAPESP, in 1962 (see FAPESP sets science free). "Scientists and politicians somehow managed to write it into the constitution that FAPESP would receive 1% of all tax receipts in the state," says physicist Sergio Rezende, who was Brazil's minister for science and technology from 2005 to 2010. "Since then FAPESP has always funded good science, and São Paulo now accounts for 40–50% of Brazil's scientific output."

Then, in 1967, the military dictatorship that controlled Brazil from 1964 to 1985 embarked on a major reform of the research sector. A new funding agency, FINEP, was set up to provide research grants to both industry and academia. "From the beginning FINEP had the role of supporting both science and enterprise," says Rezende. "It was very powerful, and provided ample grants that allowed large new physics departments to be created."

Those new departments were formed as part of a rapid expansion in the federal university system. Full-time faculty positions were created, and new graduate programmes began to train a new generation of physicists. However, progress came to a screeching halt in the 1990s, when the newly elected democratic government faced a catastrophic combination of massive public debt, hyperinflation and a stagnant economy. "In the 1990s federal funds were very short," remembers Rezende. "At one time FAPESP had more funds that FINEP and CNPq put together. It was FAPESP that kept science going in Brazil."

From the desperation of the 1990s, the growth in Brazilian science over the last 10 years has been nothing short of astonishing. Additional federal funding for research has been mirrored by increased contributions from companies and state governments, with the result that in 2010 the overall investment in R&D was four times greater than a decade earlier. Research output has followed: Brazil is now number 13 in the global rankings of published peer-review articles, with its contribution to the worldwide total rising from less than 1% at the beginning of the century to 2.7% in 2010.

"The situation now is much better now than it was 15 years ago," says Rezende, who under President Lula pushed through radical reforms in science funding, including an expanded programme of National Institutes for Science and Technology (see Seeds of change). "The science R&D budget is now $25 bn per year, which equates to 1.2% of GDP, and 40% of that total funding now comes from companies."

That additional funding is bringing fundamental changes to the Brazilian physics community. "The investment in basic physics has grown," says Eduardo Miranda, a theoretical physicist at the State University of Campinas. "That makes it possible to plan longer-term investments in research programmes."

Miranda explains that theory has traditionally dominated Brazilian physics because "it's much cheaper". Now, however, more universities are able to invest in experimental facilities and young physicists are being trained in practical techniques (see p23). As a result, there is an almost even split between theory and experiment, and in fields such as condensed matter and optics the number of experimental physicists outstrip theoreticians by three to two.

At the same time, Brazilian physics is growing in international stature. The number of physicists at PhD level has grown four-fold over the last 20 years – reaching almost 4000 in 2010 – while Brazilian physicists authored almost 25,000 research articles in international science journals between 2007 and 2010. Brazil is also taking a more active role in large research collaborations, particularly at a time when science budgets are under threat in other parts of the world (see p25). "Physics has become more important," says Rezende. "We are making good progress."

The SBF has also played its part. "The physics community was one of the first to get organized," says Melo. "The SBF was formed in 1966 and now has around 6000 members – which includes almost all research physicists plus a strong contingent of physics teachers."

**Physics at the ministry** Sergio Rezende, a physicist who was Brazil's science minister from 2005 to 2010, shows President Lula the facilities at the European Southern Observatory in Chile.

However, Brazil's scientific community hasn't been immune to the impact of the global economic crisis. The current government – led by President Dilma Rousseff – made wholesale cuts to public spending when it came to power in 2010, and the federal science budget was slashed by 9% in 2011 and a further 20% in 2012. Rezende, though, is hopeful that the last two years will prove to be a short-lived anomaly. "The budget proposal that was sent to Congress in September 2012 would restore the R&D spend to 2010 levels, so we should see a better situation if the government approves the budget," he says. "The president sees the value of science and technology; I only hope that her advisers don't spoil it."

Whatever the final settlement may be, one thing is certain: there will be a greater focus on deriving commercial success from all the investment in grass-roots science. "Physics, as well as engineering, are very special players for the Brazilian present and future," said Ronaldo Mota, secretary for technological development and innovation in the science ministry, speaking in 2011. Mota stressed that the government's plan is "to establish bridges to connect our science and technology sectors with enterprise and social demand".

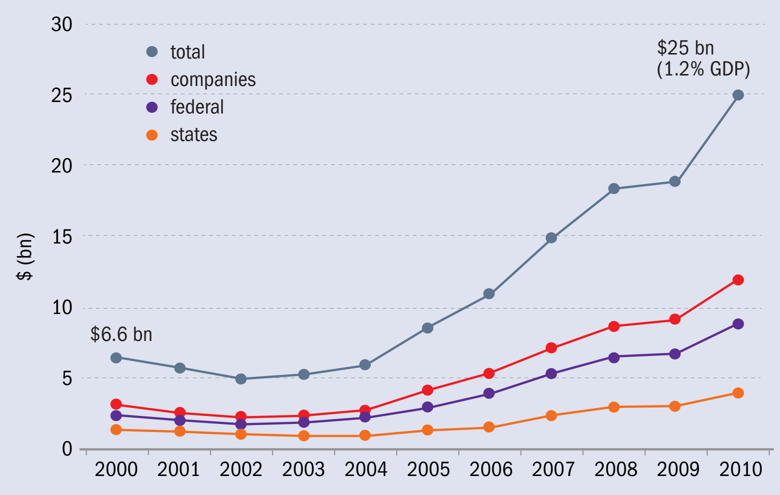
Many of the physicists I speak to are equally keen to see scientific research drive future business development. "We need to get research out of academe

## FAPESP SETS SCIENCE FREE

The state of São Paulo is the powerhouse of Brazilian science, accounting for almost half of the country's research output. The state supports three public universities – including the mighty University of São Paulo, the largest and highest-ranking university in Latin America – while by law 1% of all state tax revenues is invested in the São Paulo Research Foundation (FAPESP) to spend on research, education and innovation.

With an annual budget that now exceeds $500 m, FAPESP operates a rigorous peer-review process to evaluate project proposals. "FAPESP looks for research that either has international significance or strategic importance to the country," says Vitor de Souza, a physics professor at the University of São Paulo – and who has just sent off his latest research proposal. "If there's no expertise locally, the proposal must be written in English so it can be reviewed overseas."

FAPESP has provided something of a role model for other Brazilian states, and today there are at least 15 state-level research foundations. "When I was in government we created a programme to establish co-operation between the national and state foundations," says Rezende. "Many state governments increased funding for agencies because the federal government would also contribute funds. Now there is a national federation of state agencies that can put pressure on federal government to maintain funding levels."




**On the up** Science funding in Brazil almost quadrupled between 2000 and 2010.

and take it to the industry lab," says Miranda. "And we need to convince entrepreneurs to invest in research." One of the key issues, says Melo, is a fundamental disconnect between the research community and business owners. "People at university don't know how to handle spin-offs, and companies are suspicious of universities," he says.

Formal mechanisms have been introduced in an attempt to bring the two sides together. In 2008 FINEP introduced Sibratec, an innovation network that provides companies with access to technical expertise as well as managerial know-how. FAPESP also runs multidisciplinary centres for innovation that have yielded several successful spin-offs and commercial products. Both researchers and politicians now hope that investments in scientific infrastructure and projects will also help to drive industrial development (see p15).

### Aiming for impact

At the same time, there's a sense that the physics community needs to be more ambitious, more audacious. "We need to believe that important things can happen here," says George Matsas, a researcher at the State University of São Paulo and a scientific committee member at FAPESP. "We have people with real talent, but the last step for Brazil is to create global scientific leaders."

Matsas argues that while scientific output has grown, the impact of Brazilian research is lower than in the US and Europe. His conclusion is supported by figures released in 2012 by *Nature*, which showed that only 0.43% of all the research papers published by Brazilian scientists featured in the top 1% of most-cited articles during 2012, compared with 1.44% for the UK and 1.19% for the US. "Our impact is less than the world average," agrees Melo. "We need to improve."

Melo worries that research success is based purely on the number of papers published. "This promotes conservatism, since it's easier to publish within an established research programme than to spend time opening up new lines of research." Nathan Berkovits, the renowned string theorist who originates from the US but now works alongside Matsas at UNESP, agrees: "Researchers in Brazil are under pressure to publish. That means that lots of papers are published, but the quality isn't always very good."

Berkovits points out that many of the processes governing academic research in Brazil don't encourage excellence. "No-one from outside Brazil is involved in the committees that assess research quality. Competitions for permanent university posts are mostly decided by written exams rather than research accomplishments, while salaries are generally independent of the quality of the research."

And despite the stable funding regime, many researchers remain concerned that society doesn't recognize the value of science. There aren't many iconic physicists to fire people's imaginations, while in soap opera – Brazil's national obsession – scientists are portrayed as crazy boffins rather than normal people. "Brazil's space programme is too insignificant to mobilize public support," says Melo. "Science still isn't considered to be a tool for the strategic development of the country."

Rezende agrees that there's more work to be done. "In Brazil there are 0.8 per 1000 inhabitants working in research, compared with 2 per 1000 in the US and Europe," he says. "We need more people to justify more funds, but we need more funds to have more people."

Fortunately, the demographics are still in Brazil's favour. "Until 2040–50 Brazil will still be a young country, and more people are graduating in science as education levels improve," says Melo. Projections suggest that by 2022, when Brazil will be celebrating 200 years of independence, the country will reach the benchmark of two researchers for every 1000 inhabitants. And with the numbers of new PhD students continuing to rise, there's plenty more scope for Brazilian physics to have a worldwide impact.

### Seeds of change

Out of the funding crisis at the end of the 1990s emerged a co-ordinated approach to research management that has proved so successful that it remains in place today. "The World Bank had created so-called Millennium Institutes in Chile, and persuaded Brazil to do the same," says Sergio Rezende. "The World Bank provided half the funds to create 40 'centres of excellence', and Brazil provided the other half."

The idea was to create a network of research groups working within a specific theme. A call for proposals yielded hundreds of applications from which 40 were selected, and a further round six months later funded an additional 60 proposals. "However, the presidential aides at the time complained that there weren't 100 excellent groups in Brazil and that there should be stricter selection criteria," remembers Rezende.

That attitude changed when President Lula came to power in 2003, and as science minister Rezende reinvented the programme under the banner of National Institutes for Science and Technology. "We wanted to create a bigger programme to fund more institutes on a more consistent basis and to provide more funds to each institute."

Today, there are more than 120 national institutes operating in all areas of science and technology, and key areas of focus within physics are quantum information, complex fluids, optics and photonics, astrophysics, and organic electronics.

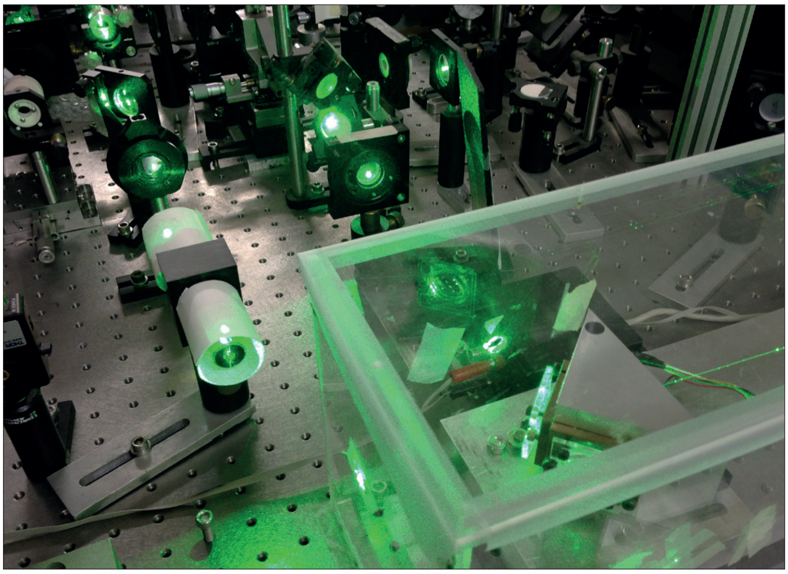
QUANTUM INFORMATION

# Optics shines in quantum realm

*An early visionary, combined with effective collaboration at home and abroad, has propelled quantum information to the forefront of Brazilian physics*

After visiting my third quantum optics lab in as many days, I start to see some of the connections that have transformed Brazil's early forays in quantum optics into a co-ordinated programme that's widely acknowledged to be producing some of the most exciting work in the field. Posters on the walls of the lab – this one is at the University of São Paulo (USP), home to one of the oldest experimental groups in Brazil – name-check several scientists I've met in other parts of the country, and researchers frequently mention long-standing collaborations with some of the most celebrated physicists in the US and Europe.

The result is a thriving community where everyone seems to know everyone else, and where collaboration and support for newer groups is valued more than internal competition. And the allure of working within that community is attracting not only plenty of students, but also – unusually for Brazil – visiting faculty from other parts of the globe.



**Three-colour qubits** Researchers at USP have used an optical parametric oscillator to entangle photons at three different wavelengths.

## Early beginnings

According to Paulo Neto, a theoretician at the Federal University of Rio de Janeiro (UFRJ), the country's current strength in quantum information stems from early work by Moysés Nussenzveig, who at 79 remains an emeritus professor at UFRJ. During his undergraduate studies Nussenzveig was lucky enough to be taught by David Bohm, a US physicist who had worked closely with Einstein at Princeton University. Nussenzveig later secured a research position with Emil Wolf at the University of Rochester, where he developed his expertise in theoretical quantum optics and became PhD supervisor to fellow Brazilian Luiz Davidovich, who now heads the quantum information group at UFRJ.

On returning to Brazil, Nussenzveig established Brazil's first quantum optics group at the Pontifical Catholic University of Rio de Janeiro. In the 1990s the group moved to UFRJ and hired young researchers to set up experimental facilities. "Today, students from that original group have become leaders elsewhere, for example to create the Enlight group at the University of Minas Gerais in Belo Horizonte," explains Neto.

The UFRJ group is now leading the way in quantum optics research. "They have obtained extraordinary success investigating spontaneous parametric down conversion," says Paulo Nussenzveig, an experimentalist based at USP – and son of Moysés.

Osvaldo Faria, a research student who shows me around the UFRJ labs, explains how the group is producing entangled quantum states that could be candidates for quantum teleportation and computation. "We use a strong ultraviolet laser to pump a bare crystal, which occasionally produces two pairs of photons, first one and then the other. This creates four-photon entangled states; if we measure one of the states the signal is destroyed, but we can access information about the entangled states by measuring the correlations between them."

**"Now, students from that original group have become leaders elsewhere"**

UFRJ is also a prime mover in the National Institute of Science and Technology for Quantum Information, the latest incarnation of a series of networks that are widely credited with developing the research base across Brazil. "Since 2001 three projects have helped to establish a nationwide competency in quantum information," explains Amir Caldeira, a theoretician at the State University of Campinas and the current co-ordinator of the National Institute. "These have provided funding for new experimental facilities and also improved the interaction between different groups."

Paulo Nussenzveig is unequivocal about the impact that these initiatives have had on quantum information research in Brazil. "There is a clear correlation between the funding of these networks and this improvement in quality and importance of our results," he says. "Our groups have been able to publish seminal papers with worldwide impact, and we have affirmed ourselves as world leaders in certain research topics."

More than 90 scientists and 20 research groups are part of the current National Institute, a five-year project that runs until September 2014. Most of the projects focus on quantum optics, while Eduardo de Azevêdo at the Physics Institute at São Carlos, part of USP, has been working with Ivan Olivieira at the Centre of Physics Research in Rio de Janeiro to investigate quantum computing based on nuclear magnetic resonance (NMR). "We can use NMR to study the basics of quantum mechanics, since it's easy to manipulate quantum states by controlling the spins," explains Azevêdo.

Funding from the National Institute is also helping Katiúscia Cassemiro to set up a new quantum optics lab at the Federal University of Pernambuco (UFPE). In recent experiments with key collaborators she first met during two European post-docs, Cassemiro has demonstrated a technique to measure the complex spatiotemporal profile of single photons. By creating and detecting multiple quantum states of light, the researchers hope to unlock more ways to manipulate quantum information, and ultimately to boost the capacity of quantum communications systems.

The importance of such international connections is a consistent theme with many of the researchers I speak to. Paulo Nussenzveig developed his experimental skills as a graduate student with Serge Haroche, who in 2012 won the Nobel Prize in Physics for developing techniques to measure and manipulate quantum light states, and today both Nussenzveig and Davidovich maintain strong links with Haroche's group. Neto at UFRJ and Marcelo Martinelli, who together with Nussenzveig heads the group at USP, also cite close connections to Claude Fabre at the Laboratoire Kastler Brossel in Paris.

According to Neto, this international exposure has been crucial for the development of quantum optics in Brazil. "It has created lots of opportunities for students, and has helped to establish the tradition of maintaining a close connection between experiment and theory," he says. "As a theorist I need to work with the experimentalists to get ideas, otherwise it's easy to get lost and go in the wrong direction."

**"Our groups have been able to publish seminal papers with worldwide impact"**

Indeed, when I speak to Martinelli late in the day at USP, he has just returned from a meeting of French and Brazilian scientists, while Nussenzveig is currently on sabbatical at Cornell University. Martinelli and Nussenzveig are keen to investigate whether on-chip optical waveguides could be used to manipulate quantum information, and Nussenzveig is gaining valuable knowledge about all-optical circuitry from the Cornell group. "On-chip manipulation is a medium-term goal to enable greater scalability of quantum systems," Martinelli tells me. "Electrical chips aren't coherent enough; an optical chip offers the coherence, but then we come up against the diffraction limit."

Today's experiments at USP aim to use entangled light beams to transfer information between atomic clouds, which could form separate nodes in a quantum network. In one lab the team is working on three-colour entanglement, in which an optical parametric oscillator (OPO) is used to convert light from a green pump laser into two correlated photons at different infrared wavelengths. Recovering the original pump beam after interaction with the nonlinear crystal allows entanglement between photons at three different wavelengths, and the team is now analysing the dynamics of the entanglement to work out the best conditions for transmission without loss.

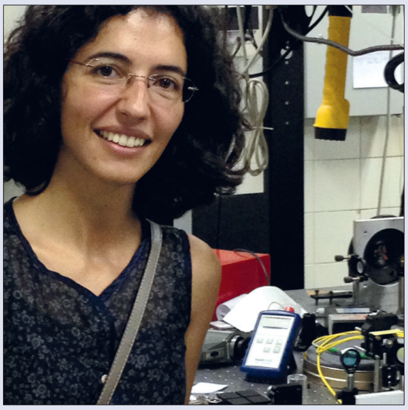
In another lab the researchers are attempting to transmit the information encoded in a cloud of cooled rubidium atoms through an all-optical system. A coherent laser beam interacts with atomic states in the cloud, and also pumps an OPO to create two entangled beams. This allows quantum information to be transferred from the atoms to the pump laser, and then from the pump to the entangled pair. One final objective is to couple the entangled light into an optical fibre for transmission to a remote station.

It's here at USP that I spot those familiar names on the walls. Cassemiro from UFPE was a research student at USP, while the cold atom work has involved close collaboration with José Tabosa and Daniel Felinto, also at UFPE. The national strategy seems to be working.

## L'OREAL AWARD RAISES QUANTUM PROFILE

Katiúscia Cassemiro, the young researcher that I met at UFPE, was the only physicist to win one of seven For Women in Science Awards in 2012. A joint initiative between L'Oréal Brazil, the Brazilian Academy of Sciences and UNESCO, these regional awards aim to support female scientists early in their career and provide a grant of $20,000 towards their research work.

"The award brought some funding, although not enough to start a whole new lab," Cassemiro tells me. "The most important thing is the recognition, since it will help me to secure funding, attract research students to join my group, and make contacts for new collaborations."



**Quantum queen** Katiúscia Cassemiro joined UFPE in 2011 to set up a quantum optics lab.

Marcia Barbosa, a Brazilian physicist who has been a powerful advocate for women in science, agrees. "These awards are wonderful because they highlight the work of very young scientists," she says. "It gives them a great start. If you follow the lives of the previous prizewinners, you can see that each of them has a successful career."

To win the award Cassemiro had to submit a proposal for a research project with some element of sustainability, and her winning idea was to study quantum systems that could enable more efficient solar cells.




PHYSICS IN AGRICULTURE

# Brazil harvests high-tech success

*Co-ordinated investment in science and technology over the last 40 years has transformed Brazil's farming sector into a booming agribusiness*

On the road from São Paulo to my destination in São Carlos, some 230 km north-west of Brazil's largest city, it's not hard to see why Brazil has become one of the largest agricultural producers in the world. Warm sunshine all year round plus short, sharp bursts of rain has created a lush, verdant landscape of rolling hills dotted with farms, crops and grazing animals. Combined with the vast expanse of land, Brazil is now the world's largest producer of coffee, sugar cane and oranges, and the number one global exporter of soya beans, orange juice, and meat and poultry.

But this farming bonanza is a relatively new phenomenon. In the 1970s Brazil was a net importer of agricultural products, with a poorly developed infrastructure and large swathes of land that could not be cultivated. Then, in 1973, the generals of the military regime set up Embrapa, the Brazilian Agricultural Research Corporation, with the aim of exploiting science and technology to transform the country's farming economy. And the plan has succeeded: Embrapa has turned millions of hectares of infertile land in the cerrado – Brazil's tropical savannah – into farmland capable of sustaining crops as well as grasses sourced from Africa for animal pasture. Embrapa scientists have also created a new tropical strain of soya bean, and pioneered "short cycle" plants that make it possible to grow two or three crops a year.

As a result, Brazil's farming sector now generates annual revenues of around $140 bn, and in the last 10 years alone exports have grown by 400% to reach around $80 bn per year. What's more, the increased output has been achieved in large part through improved productivity, which has limited the amount of extra land under cultivation. The government is now aiming to increase production of beef, soya beans and poultry by up to 30% by 2020, at a time when agricultural output in other parts of the world is either stagnating or declining.

**"Brazil is now the world's largest producer of coffee, sugar cane and oranges"**

Embrapa continues to play a crucial role in that growth strategy. With an annual budget of $1.1 bn, the organization consists of 47 research institutes that together employ more than 2500 scientists. Product research centres focus on different types of produce – everything from tropical fruits and coffee through to cattle and goats – while regional institutes seek to optimize production for the local soil and climate conditions. Other thematic units, such as the agricultural instrumentation centre where I'm headed, offer specialist expertise and skills for the Embrapa network as well as for Brazil's booming agribusiness.

"We are using physics techniques to increase profits," says João de Medonça Naime, the centre's deputy head for research and development. "Embrapa is a government-owned company: we transfer technologies to companies or industries, and they pay royalties to help fund future research."

### Agriculture meets science

The instrumentation institute was founded in 1984 by Sérgio Mascarenhas, an experimental physicist who had already set up the neighbouring Physics Institute of São Carlos (IFSC) as a science and technology institute of the University of São Paulo. The research centre now has 18 labs focusing on analytical techniques, nanotechnology and environmental science, and has collaborations in place with around 160 scientists at IFSC and other local universities.

Key analytical techniques include nuclear magnetic resonance (NMR), spectroscopy, imaging, and tomography. As an example, NMR offers a high-throughput method for assessing the amount and saturation level of oil in seeds, which dictates whether they should be used for feed or for producing biodiesel. Laser-based spectroscopy can be used to determine the chemical composition of soil and to detect disease in citrus fruits, while computerized tomography offers an insight into the physical structure of soil.

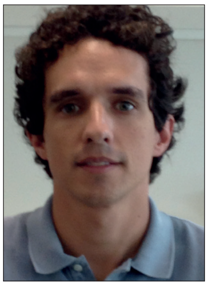
Meanwhile, environmental scientists are investigating whether urban residue such as brick and tile dust could be used as a soil conditioner, either to improve water retention or to alter pH levels. Computer models are also revealing the impact that increased $CO_2$ levels might have on pests, and how large-scale cultivation of crops such as sugar cane will affect land and water usage.

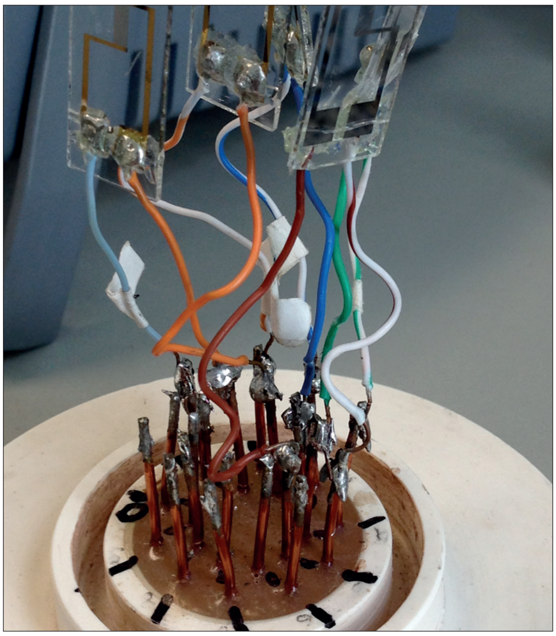
Two major areas of investment are nanotechnology and precision agriculture, both of which feature in the Great Brazilian National Challenges in Agriculture defined by Embrapa to prioritize research initiatives. "A new national laboratory for precision agriculture will open in 2013," Naime explains. "Around 200 researchers will work there to develop machinery such as robots for remote monitoring, irrigation systems with telemetry and UV-based remote sensing, which can detect problems in crops such as lack of nitrogen."

Also opening in 2013 will be a major expansion of the National Nanotechnology Laboratory for Agribusiness, which first opened in 2009. The lab provides facilities for developing prototype nanomaterials, devices and processes, and also leads a national research network investigating how nanotechnology can boost agricultural productivity. Projects include the development of plastic bio-nanocomposites, which have been used for instance to fabricate planting tubes that can biodegrade into the soil, as well as edible nanostructured films that can extend the shelf life of fruit and vegetables.

Daniel Corrêa, an Embrapa researcher who completed his graduate studies at IFSC, shows me around the nanotechnology centre. One lab is full of equipment for creating nanosized particles, films and fibres, while a neighbouring room houses a pilot production system for fabricating very thin polymer films for food packaging.

Corrêa also shows me prototypes of an electronic nose and an electronic tongue. "The human tongue collects the fingerprint of taste as electrical signals for the brain to decode," he explains. "The electronic tongue exploits an array of sensors, and each sensor is coated with a nanostructured film to give a broad





**Taste test** Daniel Corrêa is a researcher at Embrapa's nanotechnology lab and has been working on an electronic tongue to enable efficient quality control of water, coffee and wine.

electrical response for distinct analytes. When the sensor array is put into a liquid sample, we measure the electrical resistance and capacitance as we scan through the frequencies."

Such measurements allow comparison of different samples, for example to detect pesticides in water and for quality control of wine or coffee. Meanwhile, the electronic nose is designed to detect volatile compounds, such as the ethylene released by ripening fruit. "At the moment the fruit must be placed in a closed container, but the aim is to develop portable sensors that can be used in the open air," says Corrêa.

Corrêa also offers me a glimpse of the new building, which still has dozens of empty rooms waiting to be transformed into labs and offices. Additional researchers from both Brazil and abroad will extend the current work programme on sensors, edible films and bio-nanocomposites, while others will investigate new applications of nanotechnology in agriculture. There are also plans to study whether nanosized particles and fibres are safe for use in the food chain and, as with the rest of the Embrapa network, to ensure that the technologies developed at the centre are adopted in the real world by farmers and producers.

## SCIENCE MAKES PROFITS

One key focus for the Embrapa network is to ensure that new technologies are made available to farmers and agricultural producers. A notable success story from the Instrumentation centre is the Wiltmeter, a portable instrument for assessing the firmness of lettuce leaves. This technology, which works by measuring the pressure needed to flatten a lettuce leaf against a plate, was patented by Embrapa in 2007 and has since been commercialized by a local supplier of laboratory equipment.

The Ali-C food analyser developed at Embrapa Instrumentation is also being used by the Brazilian Coffee Industry Association to assess the quality of coffee powder. Pure coffee product should contain less than 1% of impurities such as bark and sticks, but producers have been known to adulterate their coffee to cut costs. The Ali-C analyser exploits the photothermal effect to identify unwanted additives in a quick and easy test that requires no pre-treatment.

Other valuable technologies that have been transferred to industry include an instrumented sphere that simulates the handling of oranges in a packing house in order to minimize losses. "We have also developed a potato classification scheme that has also been applied to coffee, a mobile unit to aid harvesting, and nutshell cracking machines," says Naime. "We transfer the technology to businesses and farmers, and we get paid royalties."

BRAZIL AT CERN

# CERN club opens its doors to Brazil

*In seeking to become an associate member of CERN, Brazil hopes to boost high-tech industry as well as physics research and education*

**Joint declaration** CERN director general Rolf-Dieter Heuer (left) with Ron Shellard of the CBPF (right) and Farani Azevêdo, the Brazilian Ambassador to the United Nations Office in Geneva.

Tucked away in a university basement a century ago, Ernest Rutherford discovered the atomic nucleus with the aid of a couple of students, a radioactive source and a sheet of gold foil. Today, by contrast, the quest to understand nature's smallest constituents demands the biggest machines ever built and resources that are beyond the means of any single country or continent.

CERN, the European laboratory for particle physics outside Geneva, Switzerland, is at the forefront of this endeavour. Straddling the French-Swiss border, it has attracted more than 10,000 users from 600 institutes in 113 countries. But not all nations represented at CERN have an equal say on what it does. The laboratory, which was founded in 1954 to help consolidate European science after World War II, is funded and overseen by 20 member states, all of which are in Europe. In the past few years, however, CERN's management has opened the door to non-European membership, and Brazil was one of the first countries to come knocking.

Brazil has long been associated with CERN, and in late 2010 the Brazilian government sent a letter to CERN to express its intention to join formally. "It opens up new opportunities to train scientists, engineers and technicians and would make our participation in what one may label as the greatest adventure of the human spirit and industriousness more concrete," says Ron Shellard of the Brazilian Center for Physics Research (CBPF) in Rio de Janeiro, who is heading Brazil's negotiations with the European lab.

Membership of the CERN club secures a country a seat on its governing council, at a price proportional to a country's GDP. Full membership is not cheap: the UK contributes upwards of \$150 m per year towards CERN's \$1.2 bn budget, for instance, in addition to the cost of particle physics research groups at home institutes. Brazil is aiming for associate membership, which allows a country to take part in council discussions but not to vote on decisions. "Each application for associate membership is negotiated directly with the country involved," says CERN's head of communications James Gillies. "The minimum an associate member must pay is 10% of what their contribution as a member state would be, but the figure can also be higher depending on what the country wants from its association with CERN."

"We are already very welcome at CERN, but associate membership will raise the status of high-energy physics in Brazil"

So far, Brazil is the only country from Latin America that has formally applied to CERN, although Mexico, Colombia and Argentina have also expressed interest. Cyprus, Israel and Serbia have recently become associate members, while Russia, Slovenia, Turkey and Ukraine are also aiming to join the club. Russia and Turkey, along with India, Japan and the US, are currently "observer" states that can attend council meetings but not take part in the decision-making process.

Money is not the most important factor for CERN when reaching out to non-European members, explains José Salicio, CERN's international relations representative for Latin America, who was part of a CERN delegation that visited Brazil in October 2012. "A country needs three main things: a solid basis in experimental and theoretical high-energy physics, both funded properly; the industry capacity to tender for CERN technology contracts; and the will of the state to co-operate," he says. "The impression I got from our visit was that at all levels Brazil wants this."

### Scientists at CERN

Brazilian physicists have been taking part in CERN experiments since the late 1980s, just as the 27 km-circumference Large Electron Positron (LEP) collider was about to start up. Specifically, a group from several institutes in Rio worked on the DELPHI experiment, one of four particle detectors located around the LEP ring. When LEP closed in 2000, some of the group moved into the collaborations responsible for the four giant detectors at the Large Hadron Collider (LHC), which now occupies LEP's tunnel.

Some DELPHI physicists joined the LHCb experiment, which is devoted to precise measurements of particles called B mesons, while others moved into the ATLAS collaboration, where Brazilian engineers had already been involved. ATLAS is one of the LHC's two general-purpose detectors designed to find new particles produced in high-energy proton–proton collisions, as they did last year with the discovery of the Higgs boson. A Brazilian group that had been working in the US at the now closed Tevatron collider at Fermilab joined the LHC's other general-purpose detector, CMS, while a group from institutes in São Paulo that had been working at the Relativistic Heavy Ion Collider (RHIC) in Brookhaven joined the LHC's ALICE experiment, which is devoted to studying the collisions of lead and other heavy nuclei.

Although CERN is responsible for its accelerators and infrastructure, the enormous collaborations that built the experiments and are now analysing the data from the LHC are self-governing bodies made up mostly of researchers from individual universities – ATLAS and CMS each have over 3000 members. Today, there are over 100 registered CERN users from Brazil: 30 on CMS, 27 on LHCb, 23 on ATLAS and 11 on ALICE, plus some theorists. Three Brazilian physicists are also involved in the non-LHC experiment ALPHA, which is dedicated to the study of antimatter.

"The experience of working in international collaborations has always been good for us," says LHCb member Miriam Gandelman of the Federal University of Rio de Janeiro. "Brazil is a very big country but we don't have the kind of contact with neighbouring countries that Europe does, so for the students it's a very rich experience to meet other students from different cultures." Individually, Brazilian researchers already contribute to CERN as if they were from a member state, says Gandelman, but associate membership will make them eligible for highly sought after CERN employment positions and student programmes. "We are already very welcome at CERN, but associate membership will raise the status of high-energy physics in Brazil because the government will be supporting formally what we do. This will bring more stability."

Crucially, associate membership would allow Brazilian industries to compete with those in Europe to supply high-tech equipment to CERN, such as that required for a planned upgrade to the LHC towards the end of the decade. A new silicon laboratory, a joint initiative among several groups in Rio and São Paulo, will be used to develop advanced silicon detectors for the CMS and LHCb upgrades, allowing better tracking of charged particles produced in the proton collisions. Brazilian physicists have considerable experience in detector construction, for instance from their work on the LEP and RHIC experiments. But until now, says Gandelman, this has mainly been done by sending researchers to CERN or other labs around the world. "It is a big change to do this in Brazil and we have the organized funding that allows us to do that now."

The silicon lab would be one of several comprising a $4.9 m Distributed High-Energy Physics Instrumentation Laboratory, which according to the project

**Join the club** Brazil hopes to have its flag flying alongside those of the other member states.

proposal will work in unison with Brazilian industry to undertake "daring" R&D projects. Semiconductor technology and electronics for the CMS and LHCb upgrades will be developed in association with CEITEC, a Brazilian for-profit public company created to develop the domestic microelectronics industry, while R&D on optical links for high-speed data transmission in the LHC's tough radiation environment will be developed in association with Brazilian optoelectronics firm PADTEC. Such technology transfer is precisely the kind of thing that CERN is looking for in new members.

The CERN delegation that visited Brazil in October is expected to report back to the council in March. "If the Council invites Brazil to join CERN – and there is no reason why it should not – the next step would be to submit the agreement to the Brazilian Congress," says Shellard. "This should happen in the first semester of 2013."

Brazil still needs to clarify how its administration and funding mechanisms are organized, according to Salicio. "There is no problem in getting adequate resources, however we are looking at the reliability and sustainability of the funding mechanisms because Brazilian groups working in the experimental programme at CERN will also have to contribute to the maintenance and operation of the experimental equipment," he says.

Unlike the present situation in many European countries, Brazil's strong economic growth is a source of comfort for CERN. In 2009, Austria – one of the 12 founding members – announced that it intended to pull out of the laboratory, to which it contributes some $30 m per year. Strong opposition from Austrian scientists forced the government to reverse its decision almost immediately.

Turkey also recently scaled down its ambitions from full to associate membership. "The discovery of the Higgs has probably helped persuade countries not to pull out," says Salicio. "The gain for CERN with non-European membership is that we formalize arrangements that already exist between certain states, and that the image of CERN is more international."

PHYSICS-BASED INDUSTRY

# Black gold kick-starts innovation

*Scientific research in Brazil has yet to drive much commercial development, but the discovery of deep offshore oil fields is now creating a hub for industrial R&D*

One of the most frequent laments I hear from physicists in Brazil is that too few scientists are employed by industry, and that all the extra activity in academic research hasn't yet formed the seeds of a high-tech economy. "We are producing more science publications, but industry development hasn't followed," says Celso Pinto de Melo, the current president of the Brazilian Physical Society (SBF). "Multinational companies have come to Brazil to take advantage of our economic growth, but they don't locate their R&D facilities here."

The one beacon amidst the gloom is the national oil company Petrobras, which plans to invest around $4.5 bn in R&D over the next five years. In 2006 the company discovered a huge offshore oil field that could more than double its proven oil reserves – which would make it one of the world's largest oil producers – but the oil is trapped underneath a 2 km-thick layer of salt that itself is 5 km below the surface of the Atlantic Ocean.

Extracting the oil from this deep pre-salt layer will push drilling and production technology to its limits, which is one reason why Petrobras now invests about 6% of its turnover in R&D. Since 2005 it has spent $700 m to upgrade and expand its research centre, CENPES, which is located on the campus of the Federal University of Rio de Janeiro (UFRJ). CENPES now has an annual budget approaching $900 m and employs around 800 graduate researchers and 300 engineers.

At the same time, Petrobras is required by law to put 1% of its income from oil production into university research programmes. That currently equates to some $300 m per year, a figure that will rise steeply as Petrobras aims to double domestic oil production to reach four million barrels per day by 2020.

Other oil operators in Brazil are subject to the same 1% rule. BG Group, a UK-based energy company that emerged from British Gas in 1999, holds stakes of 20–30% in some of the pre-salt oil fields, and in 2011 it announced that it will invest close to $1.5 bn in a Global Technology Center on the UFRJ campus. According to Damian Popolo, BG's technology manager in Brazil, the company expects its local R&D spend to increase from almost nothing in 2011 to $200 m per year by 2021.

Such significant investment by the oil companies is encouraging suppliers to establish their own research centres on the UFRJ campus. In 2010 the oil services provider Schlumberger opened its Research and Geoengineering Center to develop new strategies for using seismic and wellbore data to map the pre-salt deposits, and for improving drilling and production efficiency. With the capacity to employ around 350 staff, the centre also has experimental facilities for analysing rocks and fluids in controlled environments.

**Science for business** Petrobras has invested $700 m to expand its CENPES research centre.

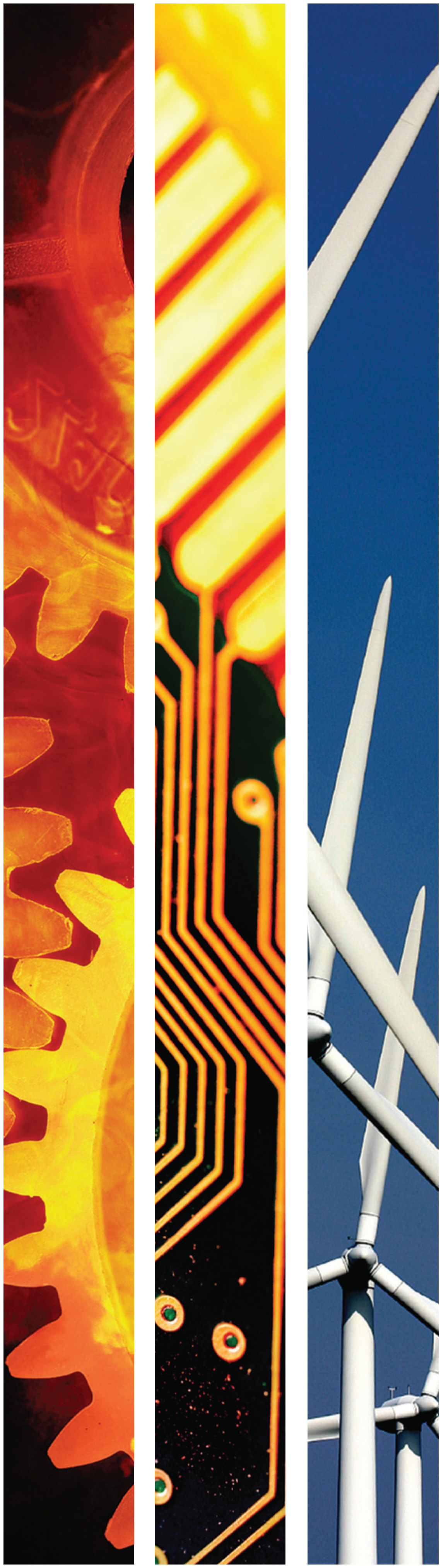
Since then FMC Technologies has opened a $40 m subsea research centre, while Baker Hughes has set up an R&D facility with the aim of optimizing the amount of oil that can be recovered from pre-salt oil reservoirs. With Halliburton, GE and Siemens among several other companies due to open research centres on the UFRJ campus soon, the state government of Rio de Janeiro estimates that overseas companies have already invested more than $300 m in the UFRJ site.

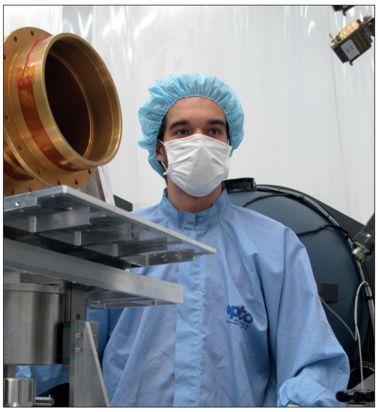
As part of their research efforts, these multinational companies will be expected to employ Brazilian scientists and create partnerships with the academic community. Schlumberger has already recruited around 50 Brazilian researchers to work at its research centre, while Baker Hughes has co-operation agreements in place with the Pontifical Catholic University of Rio de Janeiro and the University of Campinas (UNICAMP), and also has plans to fund student internships and scholarship programmes to ensure a ready supply of trained scientists and engineers.

**"Companies don't want to commit to development projects that might take 10 years to generate any profits"**

### Science stops at the lab

This influx of international investment will certainly benefit Brazil's R&D sector, but home-grown innovation remains elusive. "Successful spin-off companies are extremely rare," says Melo. "People at universities don't know how to handle innovation,





**Physics at work**
Left: a scientist in the rock physics laboratory at CENPES analyses samples recovered from a borehole.
Right: Opto Electrônica, a company founded in 1986 by researchers at IFSC, has won success in the satellite market.

and industry doesn't recognize the value that physicists can bring."

Perhaps the most obvious sign of this problem is that Brazil lacks a supply chain for scientific equipment. Researchers must usually import instrumentation from abroad, which is both costly and time consuming. One exception is BR Labs, a spin-off from UNICAMP that manufactures scientific lasers, such as the femtosecond laser that Sandra Vianna has installed in her lab at the Federal University of Pernambuco (see p23). Since 2009 the company has received two research grants to develop terahertz sources and imaging systems, which it plans to sell into the growing Brazilian security market.

Optics technology is also the driving force behind one of the largest and most successful university spin-offs, Opto Electrônica. Founded in 1986 by researchers at the Physics Institute at São Carlos, part of the University of São Paulo that's known for its focus on applied R&D and technology transfer, the company now employs 400 people and generates annual revenues in the region of $60 m.

It wasn't easy to get started, says physicist Jarbas de Castro, one of the company's founders and its current president. "For the first 10 years we hardly grew at all. We had no experience in managing a company and it took us a while to learn how." Castro says that in the early days the company failed to identify industry niches to focus on, and ended up selling key technologies to rival companies. The turning point came in 1996, when the company launched an anti-reflective coating treatment for ophthalmic lenses that now accounts for 35% of the Brazilian market. That gave the company the confidence and resources to commercialize technologies for detecting and treating eye disease, including surgical lasers and microscopes. Innovations such as a fully digital retinal camera has helped Opto to capture 60% of the domestic medical optics market.

Much of Opto's success in the medical sector resulted from state-of-the-art technology it developed for the defence and aerospace industries. In the 1990s the company worked on laser sensors for military applications such as precision target ranging, but the major step forward came in 2006, when the company won a contract to develop and supply cameras for three satellites being built by the Brazilian Space Agency. This extra funding allowed Opto to recruit 70 new researchers and invest in new production lines, as well as facilities to test satellite systems under space conditions.

There are other success stories – including laser dentistry specialist MM Optics, which was formed in 1998 by graduates from the masters degree course at the Institute of Energy and Nuclear Research in São Paulo – but they remain the exception rather than the rule. Recognizing the need to improve the situation, the state funding agency in São Paulo, FAPESP, set up multidisciplinary Centres for Research, Innovation and Dissemination (CEPIDs). As an example, one of the CEPIDs focused on ceramic materials has generated two spin-off companies – one developing technologies to analyse cosmetic products and another producing nanostructured coatings with functional properties – and has also worked with partners to develop ceramic products for use in dentistry.

## Big science drives commercial development

Meanwhile, researchers believe that increased investment in large infrastructure projects will play a crucial role in developing a scientific supply chain. An early example was the construction of the National Synchrotron Light Source (LNLS) in the 1990s, when the on-site engineering team developed most of the components and systems, and sourced Brazilian parts wherever possible. That approach is now being extended to the third-generation Sirius facility, as well as to the new Brazilian multipurpose nuclear reactor (see p18).

International collaborations also offer opportunities for Brazilian suppliers to win lucrative contracts. For the Auger Observatory, a facility in Argentina for detecting high-energy cosmic rays, the research team worked with a Brazilian manufacturer of ophthalmic lenses to fabricate a lens with a diameter of 2.2 m. "We secured some research funding to develop the lens, which was passed onto the company to hire dedicated equipment and personnel for the R&D project," says the IFSC's Vitor de Souza, one of the Brazilian co-ordinators for the Auger collaboration.

Brazil is also now partnering on the development of instrumentation for two large astronomical surveys, and in the process is gaining valuable design and engineering skills (see p25). And the country's bid to become an associate member at CERN is in part intended to offer Brazilian companies the opportunity to supply high-tech equipment to the multinational laboratory. In a sign of things to come, microelectronics firm CEITEC and optoelectronics specialist PADTEC are already working on projects related to the Large Hadron Collider upgrade (see p13).

But it's not always easy to persuade commercial enterprises to get involved. "Some of the companies I've spoken to just don't get it," says de Souza, who is looking for industrial partners to develop instrumentation for the Cherenkov Telescope Array, a ground-based gamma-ray observatory that's being planned by a collaboration of 27 countries. "They have plenty of ready customers because the economy is growing, and they don't want to commit to development projects that might take 10 years to generate any profits."

RESEARCH INFRASTRUCTURE

# Open facilities secure scie

*Brazil's national laboratories for research in materials science, nanotechnology and b*

Perhaps the most potent symbol of Brazil's commitment to its science base is the government's decision to invest in two major national facilities with a combined price tag of more than \$800 m. First to come on stream will be the Sirius synchrotron light source, a third-generation machine that will be commissioned in 2016 and open to users a year later. Then, in 2018, the Brazilian Multipurpose Reactor (RMB) will allow scientists to access the first neutron beamlines to be operated in Latin America.

Sirius will be built alongside the existing second-generation source at the National Center for Research in Energy and Materials (CNPEM) in Campinas. The new machine will operate at 3.0 GeV with a brilliance that has been designed to be 10 times greater than today's leading synchrotrons, and particular focus has been placed on producing an extremely narrow beam to enable scientists to probe fine structural detail.

"For structural biology the aim is to analyse protein crystals at the nanoscale," says Mário Murakami, a senior researcher at the Brazilian Biosciences National Laboratory (LNBio), one of four national facilities on the CNPEM site. "We need a beam with a small focal point, but it must also offer high brilliance and excellent stability."

Accelerator scientists at the National Synchrotron Light Source (LNLS) – who are reponsible for designing and building the new machine – are currently working with their counterparts at other light sources, including Diamond in the UK, to design the beam delivery system. The aim is to produce a beam with an emittance of 0.28 nm rad, compared with 2.7 nm rad for Diamond and 100 nm rad for the current Brazilian machine. "We hope that Sirius will be competitive with XFEL [the European X-ray Free Electron Laser, currently being built at the DESY site in Hamburg, Germany] for producing high-quality science, although the information that it provides on material structure will be complementary," says Murakami.

According to Antonio José Roque da Silva, director of the LNLS, one key design innovation will be the use of permanent magnets with a high magnetic field as "slice superbends". These slices will be combined with low-magnetic-field dipoles for the main beam deflection, which will enable the machine to offer hard X-ray beamlines while keeping the overall dipole radiation at low levels.

Sirius will have 13 beamlines when it opens to users

**"Neutron research is a priority for physics development in Brazil"**

in 2017, with capacity to add 27 more in the future. "The beamlines will use scattering, diffraction, spectroscopy, imaging and other techniques to resolve the structures and properties of both inorganic and organic materials," says Carlos Alberto Aragão de Carvalho Filho, CNPEM's director general. "Sirius will also be important for the oil and gas industry to find materials that can operate under extreme conditions." As a result, a partnership with the national oil company Petrobras is under discussion to provide some of the \$325 m needed to construct the light source, with the rest of the funding coming from the government, the state research foundation FAPESP, and the National Development Bank.

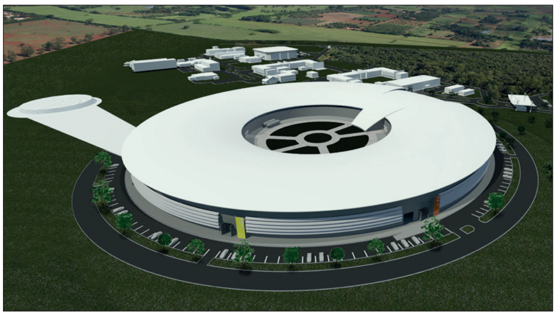
### Open facilities widen access

Even before Sirius is open to users, the four national laboratories that make up the CNPEM campus constitute the most important central resource for the Brazilian science community. Crucial to its success is the free-to-use operating model: researchers must apply to access the facilties, but all experimental and operational costs are met by the government.

The oldest and largest facility is the existing synchrotron source, a second-generation machine built and operated by LNLS since 1997. It provides 16 beamlines offering standard techniques for condensed-matter research such as X-ray diffraction and spectroscopy, small-angle scattering, and infrared

# ntific success

*iosciences are benefitting scientists throughout Brazil and Latin America*



**Open to all** The CNPEM campus in Campinas offers free access to powerful analytical tools, and will be home to the Sirius third-generation light source (top right).

microscopy and spectroscopy, while two of the beamlines are dedicated to studying the structure of biological macromolecules. Around 1400 scientists use the facility every year, with almost 20% of users visiting the facility from other countries in Latin America.

Research groups stationed at the LNLS are responsible for maintaining and developing the storage ring and the beamlines. The accelerator division designed and built most of the systems in the existing synchrotron, and over the last decade have worked on several upgrades to improve the quality, stability and energy of the beam. Now, the technical teams are developing prototype magnets and other devices for the Sirius light source, and construction is due to start in earnest in April 2013.

Also on the CNPEM site is the Brazilian Nanotechnology National Laboratory (LNNano), which offers access to a number of powerful electron and scanning probe microscopes. "Most research groups don't own their own microscope, but we can provide the equipment and the training," says Rodrigo Portugal, who has recently been recruited to develop a capability in cryo-electron microscopy. Portugal says that visiting researchers are encouraged to use the equipment themselves, but expert LNNano staff are on hand to offer advice and training.

In contrast, LNBio allows researchers in structural biology to send in their samples for analysis and access their results online. "Researchers don't need to be experts in X-ray crystallography," says Murakami. "They just need to send us a pure, stable and monodisperse sample that we screen and then prepare for analysis in the synchrotron." One of the beamlines for protein crystallography has recently been fully automated to allow thousands of samples to be analysed at the same time, which Murakami says has "really opened up structural biology research in Brazil".

Finally, the National Center for Bioethanol Science and Technology (CTBE) offers research facilities to help establish Brazil as a leader in the production of bioethanol from sugar cane. CTBE houses a pilot production facility with six multipurpose units to enable researchers to investigate different stages of the production process.

As well as offering experimental facilities to external users, each of the national laboratories have their own scientific staff and research programmes. New capabilities, such as the cryo-electron microscopy being developed by Portugal, are typically made available to internal users first, while nano- and bio-scientists relish the opportunity to analyse their samples using a variety of techniques. "This is the best facility for research in Latin America," says Andre Ambrosio, a researcher at LNBio who regularly exploits both the synchrotron light source and the electron microscopes. "We have good funding for equipment, and we can attract good students from Brazil and overseas."

### Neutrons deliver multiple outcomes

Those same scientists are eagerly waiting for the opportuntity to analyse their materials at the neutron beamlines of the $500 m multipurpose nuclear reactor, which will be built in Ipero, about 130 km east of São Paulo. The RMB's primary purpose will be to produce medical radioisotopes, which are widely used to diagnose and treat illnesses such as cancer and cardiovascular disease, but it will also allow irradiation testing of nuclear fuels and material as well as providing an open facility for neutron research.

The RMB will replace Brazil's current research reactor for producing medical radioisotopes, which is based at the Institute for Energy and Nuclear Research (IPEN) in São Paolo. "Radioisotopes made at IPEN treat 6000 patients per day, and account for 80% of the radioisotopes used by Brazilian hospitals," says Nilson Vieira, a physicist who was head of IPEN until December 2012. "But Brazil still needs to import radioisotopes at a cost of $50 m per year. The RMB should last for 50 years, so in the end it will pay for itself."

Increased output from the RMB will help to meet export demand of molybdenum-99, which is supplied to hospitals as a source of the metastable technetium-99, the most common radioisotope used in medical procedures. Over the last few years two of the world's largest producers, Canada's National Research Universal (NRU) facility and the High Flux Reactor in the Netherlands, have suffered from lengthy shutdowns due to safety concerns. "Mo-99 decays with a half life of just 66 hours, so regular production and supply is crucial," says Vieira.

Amid growing international concern in the wake of the year-long closure of NRU, the OECD's Nuclear Energy Agency was asked in 2009 to help ensure a reliable supply. "Until recently, five multipurpose research reactors, all over 45 years old, have been producing over 95% of the world's supply of Mo-99," the NEA states in its 2011 report, *The Path to a Regular Supply of Radioisotopes*. "These ageing facilities face challenges in maintaining a consistent supply to the health community."

Indeed, Canada's NRU reactor is due to be decommissioned in 2016, and the French facility OSIRIS faces closure two years later. "Canada had commissioned two new research reactors, but they will never be licensed because of design flaws," adds Vieira. Even though several research reactors in Russia and eastern Europe have joined the supply chain since 2009, the NEA still believes that the "current capacity remains fragile and further shortages can be expected".

In this context, it's welcome news that the RMB will routinely produce 1000 Curie per week of Mo-99 – about one-tenth of current worldwide demand according to the NEA – and will have the capacity to double production if required. At the moment Brazil imports about 350 Curie per week, and so RMB would have excess capacity to meet international demand.

At the same time, the RMB will offer exciting new opportunities for the scientific community in Brazil and other Latin American countries. "Neutron research is a priority for physics development in Brazil, since it will complement synchrotron techniques for detailed materials analysis," says Vieira. "Neutrons allow the analysis of magnetic properties and multilayer structures, and are particularly useful for investigating organic molecules."

**Neutron star** Nilson Vieira has ensured that the Brazil's multipurpose nuclear reactor will offer facilities for neutron science.

The 30 MW reactor will exploit an "open-pool" design, so called because the reactor core is submerged in water to provide effective radiation shielding and to produce neutrons with a broad energy spectrum. Critical design features will be modelled on the OPAL reactor at Australia's Bragg Institute, which opened in 2007 and was delivered as a turn-key solution by Argentinian company INVAP. Indeed, the entire reactor is being developed in co-operation with Argentina, while Brazil is working with Argentina on the engineering design of its new RA-10 multipurpose reactor – also due to open in 2018.

"IPEN has experience in reactor design, and around 40 nuclear engineers have been designing components for the RMB and modelling them to optimize the neutron flux," explains Vieira. "The reactor will be built by our Argentinian partners, while they also bring expertise in chemical treatments for processing the irradiated target."

The next priority is to develop a user community to specify parameters for the experimental beamlines. An initial workshop with potential users has provided the framework for a draft scientific case, while a two-week school for graduate students and post-docs in July 2013 will educate younger researchers about the benefits of neutron research. At the same time, a technical team will be formed to develop some of the core instrumentation. "We want to follow the example of the LNLS," says Vieira. "We will source commercial products where they are available, but at the same time we need to develop our own expertise in neutron science."

SCIENCE EDUCATION

# Getting the fundamentals right

*Brazil's policymakers need to prioritize science education in schools as well as in universities*

**Learning the hard way** Students leaving high school in Brazil are generally under-prepared for the rigours of an undergraduate physics course.

What you see depends on what you're looking for – as well as your vantage point. Take science education in Brazil. To the outside observer, the world's sixth biggest economy and Latin America's most populous country would appear to be in robust shape when it comes to the education and professional development of its future generations of scientists and engineers.

The headline numbers are impressive enough, especially when it comes to scientific research. In 2010, according to data from the UNESCO Institute for Statistics, Brazil's gross domestic expenditure on R&D ran to $25 bn – up from $6.6 bn in 2000. And according to Research Trends, a bibliometric analysis service, Brazilian scientists published 38,000 research papers in 2010 – 2.3% of the world's annual output of scholarly papers, and up from 1.2% in 2000.

Internationalization is another big driver. Right now, the best of Brazil's universities are on a mission to transform themselves into world-class centres of excellence for research and learning – the end-game being to boost the country's economic growth. A case in point is Science Without Borders, a $1.65 bn government-sponsored scholarship programme that aims to send 101,000 students in science, technology, engineering, mathematics and creative industries to study at top overseas universities by 2015. Heading the other way, the programme will fund a portfolio of "inbound fellowships" to bring 860 early-career scientists and 390 senior scholars to Brazilian universities and research centres over the same period.

## Back to school

On the face of it, then, the outlook for Brazil appears rosy – at least as far as tertiary education and scientific research are concerned. Scratch beneath the surface, however, and a more troubling picture comes into focus. Eduardo J Gomez, a seasoned Brazil-watcher at Rutgers University in the US, sums up the situation neatly in a Viewpoint column for BBC News Latin America and Caribbean: "Efforts to invest in youth education through the Science Without Borders programme are both welcome and much needed," he notes, "but before aspiring to build a world-renowned, technically sophisticated workforce, perhaps President Rousseff should invest more in primary and secondary schools, where the future of Brazil's scientific and technological progress truly resides."

Gomez's take is not an isolated view. In fact, the poor quality of science education in the school system is a recurring theme highlighted by some of Brazil's leading physicists, who blame low pay and lack of recognition for a chronic shortage of qualified physics teachers at high-school level. "Science education must improve across public and private schools – less than one-third of teachers who teach physics actually have a background in physics," says Celso Pinto de Melo, president of the Brazilian Physical Society (SBF). Another concern, he notes, is that "most university undergraduates currently come from private schools, and low-income students from public schools have less chance to get a good education".

Silvania Nascimento, a researcher who specializes in science education at the Federal University of Minas Gerais, concurs: "We have many problems in relation to physics teaching in Brazil – in particular, a serious shortage of physics teachers in our public schools, also the fact that physics is losing out to engineering and other better-paid professions as a career choice."

The structural problems within the teaching profession mean that students leaving high school are generally under-prepared for the rigours of an undergraduate physics course, explains Vitor de Souza, a physics professor at the Physics Institute at São Carlos (IFSC), part of the University of São Paulo (USP). For a four-year physics degree at IFSC, the typical attrition rate is such that from an intake of 120 students, Souza would expect only around 30 of the original cohort to go on to graduate. And that's despite a more rigorous selection process at USP, which receives its funding directly from the state of São Paulo, compared with the other federally funded universities across Brazil. "You've got to be passionate to survive the system," claims Souza. "Only those who are really passionate about physics will choose to make a career out of it."

**"Only those who are really passionate about physics will choose to make a career out of it"**

Even then, there's growing competition for the best graduate talent, says Antônio Azevedo, head of physics


at the Federal University of Pernambuco. "More physics graduates are now recruited by industry – particularly Petrobras and the oil companies – straight after their first degree. Many graduates also choose to work abroad for their PhD or postdoctoral experience, which contributes to a shortage of graduate students."

**School's out** CERN's Portuguese-language summer schools have been an inspiration for many Brazilian physics teachers.

### Back to basics

Clearly the shortcomings of physics education within the Brazilian school system would appear to be deep-rooted and multilayered. This will be no easy fix. More likely the road to improved standards of physics teaching and learning is going to be a long-term endeavour, one that requires co-ordinated and sustained actions across a number of key stakeholder groups – physicists, teachers, educationalists, as well as state and federal funding agencies. Encouragingly, there's growing evidence to suggest that joined-up thinking is already translating into joined-up action.

One of the most significant initiatives is a new national professional masters degree in physics teaching. The programme, which is due to launch in autumn this year, is being co-ordinated and run by the SBF and funded to the tune of around $1.5 m per year by the Brazilian Federal Agency for the Support and Evaluation of Graduate Education (CAPES). To date, 21 universities across Brazil have been signed up to run the two-year masters course, with CAPES allocating fellowships to support an annual intake of 400 students – all of whom must be practising physics teachers in middle or high school.

"The physics teachers will take the professional masters course on a part-time basis over two years, so they need to schedule the course work and dissertation around their existing teaching commitments," says Rita de Almeida, who's heading up the masters programme for SBF. One of the main drivers, explains Almeida, is the fact that physics course materials in the classroom are outdated and of variable quality. "We're trying to promote creative and progressive ways of teaching physics with the help of more engaging course materials that will be developed by the masters students themselves. It's also important to note that we're taking an inclusive approach here, working closely with the teaching community, with researchers in science education and with CAPES. We expect the masters programme to have a huge impact on physics education across Brazil."

**"We're trying to promote creative and progressive ways of teaching physics"**

On a smaller scale, the CERN Portuguese Language Teachers' Programme represents another notable contribution to the professional development of Brazil's physics teachers. Over the past six years, a total of 82 Brazilian high-school teachers – along with nearly 300 of their peers from Portugal and other Portuguese-speaking nations – have attended an intensive teaching update programme held each summer at the CERN particle physics laboratory in Geneva.

During the week-long session, the teachers attend lectures and workshops delivered by Portuguese-speaking scientists on a range of cutting-edge topics, including the basics of particle physics, cosmology, astroparticle physics, data acquisition and medical physics. Those lectures are complemented by hands-on activities at CERN's accelerator and detector installations. The programme is a win–win: physics teachers return home fired up by their interactions with CERN scientists and colleagues from other countries, while CERN reinforces its relationships with a number of developing countries – a useful exercise in the laboratory's efforts to become a truly global initiative.

### On the right track

At the political level, Brazil's federal government has a number of mechanisms through which it can actively promote science education. The national teaching initiation programme, for example, awards scholarships to students embarking on teacher-training courses, as well as providing a significant salary uplift to the teachers who work with and mentor these students in their classrooms. "Other government programmes aim to spot and develop scientific talent early by identifying high-school students with a strong vocation for scientific research," says Nascimento. "As well as gaining access to scholarships to fast-track their studies, these students will often get to work directly with academic advisers in the research community."

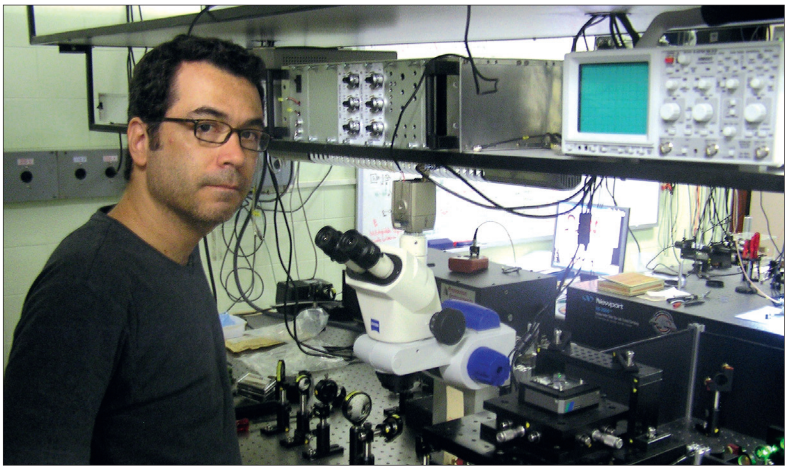
There may be a long way to go, but there's already enough momentum to suggest that Brazil is poised to make serious headway in tackling the shortcomings in physics education across its public and private school systems. One thing is certain: getting the fundamentals right in science education is going to be a prerequisite if Brazilian scientists are to deliver against the recent call to action from Marco Antônio Raupp, Brazil's science minister. "Our challenge is to transform science, technology and innovation into the protagonists of Brazilian development," he notes. "We are living a special moment, where there is acknowledgement of important sectors of society in relation to the role that science and technology must carry out."

Time to get busy.

EXPERIMENTAL PHYSICS

# Scientists put theory to the test

*Stable funding plus improved training are providing a new generation of physicists with the skills and resources to excel at experimental research*



**DIY science** Leonardo Menezes built his confocal microscope from standard components.

Leonardo Menezes is so excited about his new laboratory at the Federal University of Pernambuco (UFPE) that he seems more like a young boy in a sweet shop than a physics researcher. Menezes, who joined UFPE after post-doc experience with Oliver Benson's nano-optics group at Humboldt University in Berlin, spent five years installing and configuring equipment to study how spherical microcavities alter the way that light propagates. Now, he modestly says that his lab is "very well equipped compared with other nano-optics facilities that I've seen".

Menezes is one of several young experimental scientists in the optics group at UFPE. He's in good company, says Sandra Vianna, a seasoned researcher who has been experimenting with non-linear optics and atomic systems for more than 25 years. "Optics started a long time ago in this department, and we now have a good group with good students. We discuss, we help each other, we work together on different projects."

That spirit of collaboration is important in Pernambuco, a state in the north-east of Brazil where funding and resources are more difficult to secure than in the richer states of São Paulo and Rio de Janeiro. Experimental scientists here have become adept at making their research grants stretch as far as possible. "Sometimes we share funds to buy equipment, and we also borrow from other groups for particular projects," says Vianna.

Menezes favours a do-it-yourself approach, and is particularly proud of a confocal microscope that he built from standard optical components for half the price of a commercial instrument. "It provides good opportunities for students to get to grips with experimental techniques, and to really understand how the equipment works," he says. "The Brazilian approach is to be more flexible. We need to improvize to get our experiments up and running."

Building from scratch also avoids the need to import equipment, which is a notoriously bureaucratic process in Brazil. "It's very hard to spend research funds. It's public money, so we need to justify each purchasing decision," says Edilson Falcão-Filho, another young UFPE researcher. "It can take six months or more to import equipment, and by then the field may have moved on."

Vianna was lucky enough to source a femtosecond laser from a Brazilian manufacturer called BR Labs, a spin-off from the State University of Campinas. "We're using the laser as a frequency comb to understand the interactions between light pulses and an atomic system," she explains. "I'm very happy with my laser because it's not a black box; I understand how the laser was built and it's easy to adapt and customize for my experiments."

However, a quick glance around any physics lab in Brazil reveals that most experimental scientists rely on equipment imported from the US and Europe, as there are very few domestic manufacturers of research instrumentation. And even when the kit is bought and delivered, it can take a while to get the experiments up and running.

Falcão-Filho, for example, has recently secured funding for a project to generate higher harmonics in the extreme ultraviolet regime, a promising technique for creating attosecond light pulses that could be used to study biochemical processes. When I visit in December 2012 the apparatus for his project was packed in boxes underneath the bench.

"I don't have a graduate student working with me to help install and configure the equipment," Falcão-Filho explains. Katiúscia Cassemiro, who joined UFPE in 2011 to set up a quantum optics lab, is also struggling to get started without support from research students. "It's frustrating because the pace of progress can be very slow."

Despite these hurdles, the UFPE researchers display genuine passion for their work, and regularly get their results published in top-tier journals. "I'm really enjoying what I'm doing now," says Vianna. "I love to put together the experiments with the theory to explain the results. For me the situation is now beautiful."

**"The Brazilian approach is to be more flexible. We need to improvize to get our experiments up and running"**

## Science city drives expansion

The picture is quite different at the Physics Institute of São Carlos (IFSC), part of the University of São Paulo and located some 200 km inland from Brazil's largest city. Buoyed by steady and reliable funding from FAPESP – the funding agency for the state of São Paulo – the campus here has become one of the leading centres for experimental physics in Brazil. "There's nothing to do in São Carlos except science," says Vitor de Souza, a physics professor at IFSC. "There are more PhDs per head of population than anywhere else in Brazil."

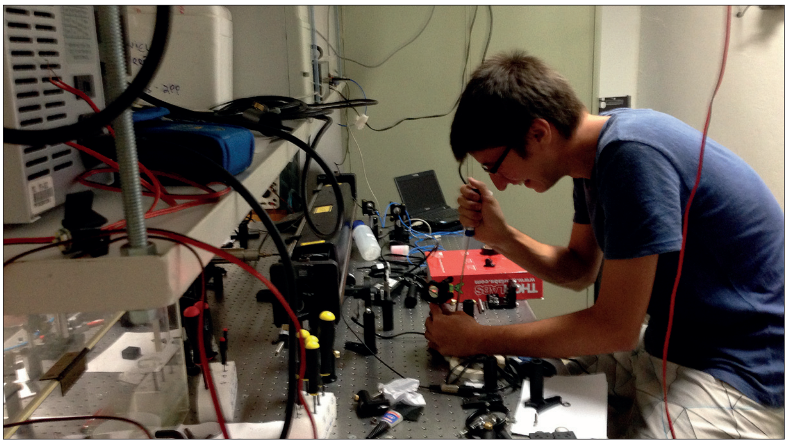
Souza tells me that IFSC was founded as a science and technology institute by Sérgio Mascarenhas, a renowned experimental physicist who went on to establish the Embrapa Institute for physics-based agricultural research in São Carlos (see p11). Today, the Institute is in rude health: the physics faculty has grown from 50 to 80 in the last 15 years, and a new building is being prepared to enable further expansion. The scientists here can bypass the bureaucracy that hampers progress at government-supported universities such as UFPE, while there's no shortage of graduate students because FAPESP pays more for PhD fellowships than the federal funding agencies.

The experimental rigour at IFSC extends to its undergraduate courses. Souza shows me a series of teaching labs that are permanently set up to allow undergraduates to explore key breakthroughs in modern physics. When I visited, one student was investigating Planck black-body radiation, and other rooms were set up to enable independent study of Millikan's oil-drop experiment, electron diffraction, and so on. "It's great to have these facilities for students, but it takes a lot of money to provide all the equipment," says Souza.

IFSC, in common with other universities in São Paulo state, also runs a programme called "scientific initiation", which offers undergraduates the chance to work on small projects in the research labs. Cleber Mendonça, who leads the large and well regarded optics group, says that the undergraduates enjoy this taste of experimental research so much that sometimes he must remind them not to neglect their other studies.

Mendonça and colleagues are using lasers to probe the properties of conjugated polymers and other organic molecules that could have applications in optoelectronics, and are also using femtosecond lasers to create nanostructured surfaces. "A non-linear reaction between the light and a resin drives a polymeric reaction to form a 3D structure," Mendonça explains. "We can dope the structure with optical, biological or electronic properties to create functional devices such as a micro-optical memory."

Elsewhere, Eduardo de Azevêdo is using nuclear magnetic resonance (NMR) to investigate how the molecular properties of polymer and protein molecules influence their electronic behaviour. He shows me an imported cryo-cooled superconducting magnet system that achieves the high magnetic fields of up to 4 T that he needs for these studies, as well as a home-made NMR device that operates at much lower magnetic fields. "We can use this device to study porous media, such as oil movement in a rock, and one particular project has revealed how biodiesel can attack polymer cross-chains in rubber compounds," he says.



**Training talent** Programmes such as Science Initiation are providing young scientists with early exposure to experimental techniques.

## Start small, become big

IFSC and UFPE both have a long tradition in experimental physics, but until recently they have been the exception rather than the norm. And even at these institutions the focus has largely been on fields such as optics and materials, where components and equipment are relatively affordable.

That's now changing, thanks to sustained investment in scientific research and infrastructure at a federal level as well as for individual states such as São Paulo. "The big shift in recent years is that Brazil has become a partner in new galaxy surveys," says Raul Abramo, a cosmologist at USP who clearly relishes the opportunity to extend his theoretical studies into the observational domain. "The ability to invest in these large projects needs a steady and reliable source of funding, and that's now been in place for the last 10–15 years." Abramo tells me that to begin with Brazil simply provided funding in exchange for access to observational data, but Brazilian scientists are starting to design and build instrumentation for newer cosmological surveys (see p25).

**"The ability to invest in these large projects needs a steady and reliable source of funding"**

The rise of experimental physics has also been helped by government support for a series of national facilities. Most significant is the National Center for Energy and Materials Research (CNPEM) in Campinas, which houses a synchrotron source as well as national labs for nanotechnology, structural biology and bioethanol production (see p18). Crucially, all the labs on the CNPEM campus are run as open facilities that allow any scientist in Brazil to access specialist equipment and expertise free of charge, a model that's now been extended to other national facilities such as the Northeast Center for Strategic Technologies (CETENE) in Recife.

There's no doubt that momentum is gathering for this new generation of experimental scientists. A stable funding regime, combined with dedicated training in experimental techniques and free access to specialist infrastructure and equipment, heralds the start of an exciting new era for experimental physics in Brazil.

**INTERNATIONAL COLLABORATIONS**

# All the world's a stage

*Extra investment in international projects is opening up new opportunities for Brazil's business community as well as for academic researchers*

International co-operation has always been a crucial catalyst for Brazilian science. When the first generation of physicists emerged from early undergraduate courses, they had little option but to develop their research careers overseas. "In the 1950s the attitude in government was that science is expensive and that there was no need to invest in a domestic science base," explains Celso Pinto de Melo, the current president of the Brazilian Physical Society. "The approach then was to provide fellowships to the most promising scientists to enable them to work at the most prestigious institutions abroad."

Even now that Brazil has invested in developing its own scientific credentials, a period of time spent abroad has become a rite of passage for many research physicists. "In the past many scientists would have gone abroad for their graduate studies," says Vitor de Souza at the Physics Institute at São Carlos (IFSC), part of the University of São Paulo. "We now have good graduate programmes, but most researchers need to have some international post-doc experience to secure a permanent faculty position."

That's certainly the case for many of the younger researchers that I talk to. Leonardo Menezes at the Federal University of Pernambuco (UFPE) studied for his PhD in Brazil and then spent two years in Germany as a post-doc before joining the university's physics faculty to establish a nano-optics research lab. Meanwhile, Daniel Vanzella, an up-and-coming theorist at IFSC, gained his post-doc experience at the University of Winconsin-Milwaukee with Leonard Parker, who in the 1960s pioneered a semi-classical theory of quantum gravity.

The benefits of such international exposure are obvious: young Brazilian scientists gain valuable skills and experience with world-leading research groups, which they can then exploit on their return to initiate new research fields in Brazil. Equally important are the international contacts that they develop at this early stage of their career, and many go on to have long-standing collaborations with their overseas colleagues


**Research goes global** Brazilian scientists have a long tradition of working with partners from other parts of the world.

that continue to stimulate research ideas long after their return to Brazil.

Menezes, for example, has maintained close links with Oliver Benson's nano-optics group at Humboldt University in Berlin. "When I first arrived at UFPE this collaboration allowed me access to experimental equipment that wasn't available to me in Brazil," he says. Menezes has gone on to publish several high-profile research papers with the Humboldt group, and Benson is keen to spend some time at UFPE as a visiting professor. Vanzella, too, has been inspired by his early work with Leonard Parker to make important discoveries about quantum effects in gravitational fields (see p31).

The benefits to Brazilian science are so significant that the government has launched the far-reaching Science Without Borders initiative, thought to be the brainchild of the Brazilian president, Dilma Rousseff. This ambitious programme aims to send 101,000 of the best Brazilian students and researchers to leading institutions around the world by 2016, when Rousseff's term comes to an end. Scholarships are available to undergraduate students as part of a sandwich course, while PhD students can either spend a year overseas or complete their full PhD abroad.

With this programme the Brazilian government believes that it can revolutionize the country's research base, and most scientists I speak to applaud its aims and objectives. As well as knowledge exchange and the formation of ongoing international partnerships, one key goal is to expose young scientists to research

environments where there is a culture of innovation leading to commercial outcomes – something that Brazil desperately wants to emulate.

Part of the programme is also aimed at attracting leading scientists to come to work in Brazil, with generous funding available for both early-career researchers and more senior scientists to complete a two- or three-year research programme. A key target for the "young talents" element of this scheme are young Brazilians who are currently working overseas, such as Luiz Bertassoni, an MIT-Harvard researcher I meet in Boston, US. Bertassoni is quite happy where he is, but says that "if I ever wanted to return to Brazil, now would be a good time".

### Beyond the borders

Increased government funding for scientific projects is also transforming Brazil's role in large international collaborations from mere participant to a strategic partner with greater influence over experimental design and outcomes. At CERN, for example, Brazilian scientists have long been involved in each of the major experiments, but impending associate membership will formalize the government's commitment and open up new opportunities for Brazilian companies to supply instrumentation to CERN (see p13).

Brazil is also one of 17 partners in the Auger Observatory, a facility in a remote part of western Argentina for studying ultrahigh-energy cosmic rays. Souza, one of the Brazilian co-ordinators for the project, tells me that Brazil became involved right at the start of the project in 1995 because of the country's long history in cosmic-ray research. "In the late 1940s César Lattes, the first well known Brazilian physicist, worked with Cecil Powell at the University of Bristol in the UK," he says. Together Powell and Lattes worked on techniques to detect atmospheric cosmic rays, which led to the discovery of the $\pi$ meson – for which Powell was awarded the 1950 Nobel Prize for Physics.

According to Souza, the Auger Observatory offered the first opportunity for Brazilian companies to supply technology to a major international project. "Brazil supplied a lens with a diameter of 2.2 m diameter, and also manufactured and supplied half of the water tanks needed for the project," he explains. Souza is hoping to repeat that success with the Cherenkov Telescope Array, a ground-based gamma-ray observatory that's currently being planned in a collaboration of 27 countries.

### Collaborations look to the sky

While Brazil has a long tradition in cosmic-ray experiments, it is a relative newcomer to observational cosmology. "In recent years Brazil has become a partner in new galaxy surveys," says Raul Abramo, a cosmologist at the University of São Paulo. "Brazil has been able to invest, and at the same time there's demand from the international community for additional funding."

For existing projects, such as the US-led Sloan Digital Sky Survey and the Dark Energy Survey, Brazil has provided some funding in exchange for access to the data. For newer projects, however, Brazil has been involved right from the start of the design phase. "We are now contributing instrumentation to international projects, which means that we understand exactly how the instrument works, what can be extracted from the data, and the limitations of the experiment," explains Abramo.

**"Brazil is a country of immigrants, and treats foreigners very well"**

Two notable projects are underway. SuMIRe (Subaru Measurement of Redshifts and Images) is a Japanese-led astronomical survey that will study dark energy and galaxy formation, and Brazil is leading efforts to build four multi-object spectrographs capable of measuring 2400 spectra at the same time, as well as an optical fibre system to relay light from the telescope to the spectrographs.

Brazil is also teaming up with Spain on J-PAS, the Jalavambre Physics of the Accelerating Universe Astrophysical Survey, which aims to measure every galaxy and star in one-fifth of the sky. For this $50 m project, Brazilian scientists are designing and fabricating the largest CCD camera plus the optical filter system. "We have been working with e2V, a UK manufacturer of CCD image sensors, to design the chips for the camera," Abramo says. "The filter system is also key: the Dark Energy Survey has five filters to take images in different spectral ranges, but J-PAS will divide the visible range into 50 different colours. This will provide excellent redshift for all galaxies, leading to radically different science."

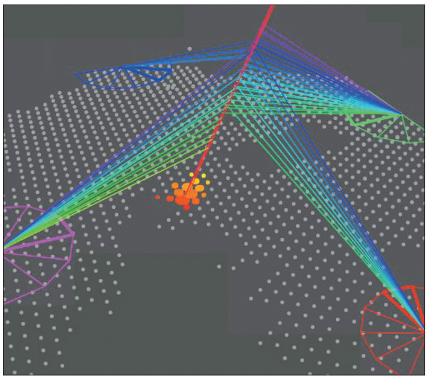
Such large-scale projects are clearly raising Brazil's international profile, but it still struggles to attract talented students and researchers from overseas. "Around 25% of our students are from other countries," says Antônio Azevedo, head of physics at UFPE, which has one of the best graduate programmes in the country.

### Society opens its doors

Within the Brazilian Physical Society (SBF), one of the key changes in recent years has been a greater focus on developing physics throughout Latin America. "Brazil is becoming one of the largest science producers, but we don't want to be detached from the rest of the region," says Celso Pinto de Melo, the current SBF president. "We want our neighbours to be part of this effort for the advancement of science."

Melo says that the SBF raised $100,000 from the Brazilian government to establish a Latin American physics programme, which included graduate workshops, training for high-school teachers, a series of distinguished lectures, and inter-country exchanges. "We also arranged a two-week workshop for undergraduates at the Federal University of Latin American Integration, which is strategically located at the symbolic border between Brazil, Argentina and Paraguay."

Melo is also keen to develop links with Africa – in particular those countries where Portuguese is the native tongue – and the SBF has played an important role in establishing a series of physics conferences for the community of Portuguese-speaking countries. Another major coup is an exchange agreement with the American Physical Society. "Brazil sends five researchers and ten graduate students to the US, and crucially the US sends the same number to work in Brazil," he says. "This helps to foster scientific collaborations that will shape their research careers."



"It's fairly easy to attract students from Latin America, but more difficult from Europe and the US."

George Matsas of the State University of São Paulo (UNESP) and a senior voice at the state funding agency, FAPESP, is also keen to attract more visiting scientists to the region. "FAPESP is happy to support European and American projects, provided there is some link to one of the universities in the state," he says.

But according to Nathan Berkovits, a celebrated string theorist originally from the US and who has been working at UNESP for many years, Brazil still makes it hard for overseas researchers to compete for permanent posts. "There's usually an open competition for faculty positions," he explains. "Candidates must sit an exam on degree-level physics, prepare a lecture for teaching, and give a seminar on their research. But most universities set the exams in Portuguese."

**Cosmic collaboration**
Brazil is one of 17 countries working together at the Auger Observatory in Argentina (above left). A cosmic ray event viewed by all four of the Auger's fluorescence detectors (right).

Berkovits has introduced an alternative recruitment method at a new regional institute set up in a joint venture between FAPESP and the International Centre for Theoretical Physics (ICTP) in Trieste, Italy. At the ICTP South American Institute for Fundamental Research, there is an international search committee composed of leading scientists from around the globe. "We publish a call for CVs with letters of recommendation, followed by an interview. Then we can have a good competition."

For international scientists who may be interested in working in Brazil, Berkovits offers some encouraging words. "Brazil is a country of immigrants, and treats foreigners very well. I originally came here for family reasons, but wouldn't have stayed if I hadn't enjoyed it."

MEDICINE AND BIOLOGY

# Physicists tackle the living world

*Multidisciplinary studies are yielding new insights into cell growth and behaviour, as well as more effective techniques to study and treat disease*

Experimental work in biological physics in Brazil can be traced back to the early 1970s, when Sérgio Mascarenhas studied polarized biopolymers at the Physics Institute of São Carlos (IFSC) and George Bemski pioneered molecular biophysics at the Pontifical Catholic University of Rio de Janeiro. Although the field has been dominated by theory since then, in more recent years there has been a gradual shift back to those experimental roots.

A reflection of that trend can be found at the Federal University of Rio Grande do Sul (UFRGS) in Porto Alegre, in the far south of Brazil. Led by physicist Rita de Almeida, researchers in systems biology predict the behaviour of cells and organisms using theoretical models that treat the proteins, metabolites and other biomolecules in a given system as a complex, interactive network. Experimental data is crucial to validate the theoretical findings, which Almeida says is sourced from several large international databases in addition to an in-house cell culture laboratory.

Other groups in Brazil are exploiting inter-disciplinary collaborations with biomedical and biological scientists. For example, a joint project with a pharmacologist proved vital in the development of a new imaging technique by Oscar de Mesquita and his team at the Federal University of Minas Gerais (UFMG) in Belo Horizonte. Like many physicists with a background in non-equilibrium dynamic systems, Mesquita was drawn towards biologically motivated research questions. "Biological materials are magnificent examples of non-equilibrium systems," he says.

The physicist was experimenting with ways to study the cellular process of phagocytosis – which allows cells to ingest nutrients and other particulate matter – with the eventual goal of exploiting the process for drug delivery. Peering through a defocused microscope, he could make out half-micron-thick sections of cell membrane that would normally be invisible. This led to a new technique, defocusing microscopy, which has since been refined and used by researchers at UFMG to investigate cell behaviour and to study the properties of red blood cells.

Interdisciplinary collaboration is also thriving in experimental structural biology, a field that straddles the fine line between physics and biology. Richard Garratt at the IFSC is a biochemist by training, but has an intimate knowledge of the physical techniques that he uses, such as X-ray crystallography and nuclear magnetic resonance, to unlock the structural secrets of complex biological molecules and systems. "I don't feel out of place as a biochemist in a physics institute," he remarks.

ACO/CNPEM

**Open research**
Students at LNBio prepare biological samples for analysis at Brazil's synchrotron source.

Stand-out projects by Garratt's group have included fundamental investigations of septins, a group of filament-forming proteins that act as cellular scaffolds and diffusion barriers. X-ray crystallography enabled the researchers to solve the structures of several septins to an unprecedented resolution. "Our work has gained us a strong international reputation in this area of structural biology," says Garratt. The group also helped develop a vaccine for the parasitic disease schistomiasis; the vaccine completed phase I clinical trials last year.

Garratt counts geneticists and immunologists among his collaborators, in addition to physicists who have migrated into the field. Andre Ambrosio of the Brazilian Biosciences National Laboratory (LNBio) in Campinas, and Garratt's former PhD student, is one such physicist. He runs an interdisciplinary group studying the metabolism of cancer with biologist colleague Sandra Dias.

In one major project, the researchers combined X-ray crystallography, protein biochemistry, biophysics and cancer cell models to examine how a group of proteins called glutaminases influence tumour metabolism. They discovered that one particular protein, Glutaminase C, plays a key role, and reported their findings in the *Proceedings of the National Academy of Sciences* last year. "This important glutaminase is now actively being investigated by drug companies," says Ambrosio.

While experimental research in biological physics is making a comeback, Brazilian researchers continue to produce quality theoretical work. Thadeu Penna of the Fluminense Federal University (UFF) in Niterói in the state of Rio de Janeiro is a computational physicist working on diverse applications of mathematical modelling. His most widely cited work is a simple computer model that accurately simulates the aging of a population, which has been widely adopted by the international research community. Penna himself is using the model to study the relationship between age and disease propagation, and between age and treatment success in tuberculosis and AIDS. "We are studying the aging-specific aspects of these diseases [to determine if] some ages are more responsive to treatment or more susceptible to infection," he explains.

Penna is largely positive about the transformation in Brazil's research environment over the last two decades. He describes being "dejected" with the physics community in Brazil after returning from a post-doc in the US in 1999. "Now, it has changed completely, in part due to the Brazilian government's efforts, but also due to state support agencies that have become more active in the past few years," he says. Garratt concurs, saying changes have been "universally positive", though he admits challenges remain. "We need to be advancing technologically, not just scientifically. We need in scientific terms to be improving quality and we still need to grow in terms of critical mass and infrastructure."

## Medical applications drive industry

While scientists such as Almeida and Penna are attempting to understand the fundamentals of biological systems, physicists are also playing a crucial role in multidisciplinary medical research. One key success story has been biophotonics, in particular for dentistry applications. "Brazil is recognized worldwide in laser and light in dentistry, from basic to applied research as well as in clinical use," says Denise Zezell, of the Institute of Energy and Nuclear Research (IPEN) in São Paulo, which is also the country's leading centre for producing radiopharmaceuticals (see p18).

Zezell says that close collaboration with dentists, biochemists and other physicists has been instrumental in her research, which has included the development of a clinically proven non-invasive laser technique that prevents tooth decay. Financial support provided by the state research foundation, FAPESP, in addition to government funding, has also been "decisive" in the success of her research.

Other key groups funded by FAPESP are two Research Centres in Optics and Photonics (CePOF), one at the IFSC and the other at the State University of Campinas. Photodynamic therapy for treating skin cancer is a central research theme at the IFSC, and its record on innovation is impressive. "We have about 14 products launched on the market together with Brazilian partner companies," says director Vanderlei Bagnato. "We also have about 12 spin-off companies and five national programmes that are developing and implementing new technologies."

But Oswaldo Baffa, a physicist at the University of São Paulo's Ribeirão Preto campus, says medical physics in the country is still young when it comes to clinical research, particularly in more traditional fields like radiation therapy. "At present we have a lot of research that is more academic-oriented," says Baffa. "Only recently people are starting to become aware of clinically-oriented research."

**Probing epilepsy** Oswaldo Baffa (left) and neuroradiologist Antonio Carlos dos Santos are part of a collaboration using MRI to study epilepsy.

Baffa specializes in magnetic resonance imaging (MRI), biomagnetism and clinical dosimetry, and is one of 12 physicists working in a multidisciplinary state-wide programme that's using MRI to investigate epilepsy. "The idea was to improve the quality of our equipment in MRI and have a large number of subjects studied in the same equipment and conditions," says Baffa. The programme includes clinical and technical projects and already has "a wealth of data" that has been collected using state-of-the-art 3 T scanners across four institutions.

Brazil also has several research groups in the core medical physics discipline of radiation dosimetry. Successes at the Federal University of Pernambuco (UFPE) in Recife have included the CALDOSE_X software, which is now used in more than 40 countries to calculate the dose for diagnostic X-ray exposures. But perhaps a more valuable contribution is the development of new semiconductor detectors for quality assurance programmes in Brazilian hospitals. "This equipment is important for our country and the Latin America region because it is expensive to import equipment and maintain it," says group leader Helen Khoury.

Khoury points to a lack of funding for Brazilian companies as a primary factor preventing the transfer of her group's technology into industry. Baffa agrees, but is hopeful that the situation will improve with the first funding round for the medical, hospital and dental equipment arm of Sibratec – an innovation network set up by the federal funding agency FINEP to convert academic knowledge into industrial development – due to come on stream this year.

In broader terms, Baffa says serious challenges still remain, including shortages of medical physicists and a lack of professional regulation. "This is highly motivating and the necessary changes could be accomplished," he says. "I am optimistic for the future: for someone that has lived under high inflation and with economic uncertainties, the present situation with steady funding is a paradise."

THEORETICAL PHYSICS

# Quantum questions spur progress

*With no more than a blackboard and access to a decent computer, Brazilian physicists are making major contributions to theoretical studies of quantum effects*

**Neutron star**
Ultradense neutron stars, typically formed when a supernova explodes as shown in this artist's impression, could become unstable when the quantum vacuum "awakens".

Daniel Vanzella says that he's known among his colleagues and students as "the black-hole guy". With his boyish good looks and easy charm, he's also becoming known within media circles as the go-to person for explaining weird phenomena in the cosmos to a general audience. But Vanzella is also playing a key role in the attempt to combine two theoretical cornerstones of modern physics: quantum mechanics and general relativity.

"We have been able to quantize everything except gravity," he explains, when I met him in his office at the Physics Institute of São Carlos, part of the University of São Paulo. "We don't yet have a full quantum gravity theory, so instead we try to add some elements of quantum mechanics to classical gravitational theory to see if any new effects emerge."

This approach, known as quantum-field theory in curved spacetime, was originally proposed by Leonard Parker of the University of Winsconsin-Milwauke in the late 1960s. "The most important result to emerge from this theoretical framework was Stephen Hawking's discovery that particles can be created by the strong gravitational fields associated with black holes," Vanzella continues.

Vanzella, who worked as a post-doc with Parker a decade ago, is now investigating whether this semi-classical approach could explain crucial open questions in cosmology, such as the nature of dark energy and the accelerating expansion of the universe. He believes that the answer could lie in the energy of the quantum vacuum, which is thought to arise from the fleeting appearance of particle–antiparticle pairs.

"They appear and disappear so quickly that we cannot see them, but these particles have energy so we can see indirect effects," explains George Matsas at the State University of São Paulo (UNESP), Vanzella's PhD supervisor and now a key collaborator. Usually the vacuum energy is very small, but Vanzella and his research student William Lima calculated that large concentrations of mass can cause exponential growth in the vacuum energy density. With help from Matsas, they discovered that ultradense neutron stars could trigger this "awakening" of the quantum vacuum.

"Neutron stars are so dense that they can distort spacetime," says Vanzella. "Within one-thousandth of a second the vacuum energy in the region of a neutron star can grow from almost nothing to become so large that stars within a certain size and mass range could become unstable." They don't yet know what might happen to a neutron star under such extreme conditions, but Vanzella believes that the finding offers important clues for future research. "If we find a neutron star with a size and mass that we think should be unstable, we would be able to rule out certain types of quantum field," he says.

**"Often there are more theorists because they require less funding"**

### From spacetime to strings

Working alongside Matsas at UNESP is Nathan Berkovits, an American who moved to Brazil in 1994. Berkovits is noted for his contributions to superstring theory, which many physicists believe is the most promising route to a truly unified theory of quantum gravity.

Berkovits has in the past worked at Cambridge University with Michael Green, one of the pioneers of string theory, and at Princeton University alongside Ed Witten, but he enjoys his research life in Brazil. "If I had stayed in England I would have been in a

big group," he tells me. "Here I have a small teaching load and the freedom to work on anything I want." Berkovits explains that the IFT is relatively small, with around 20 professors plus their research students, but no undergraduates. "People here are only interested in physics research. All our activities are related and there are fewer distractions."

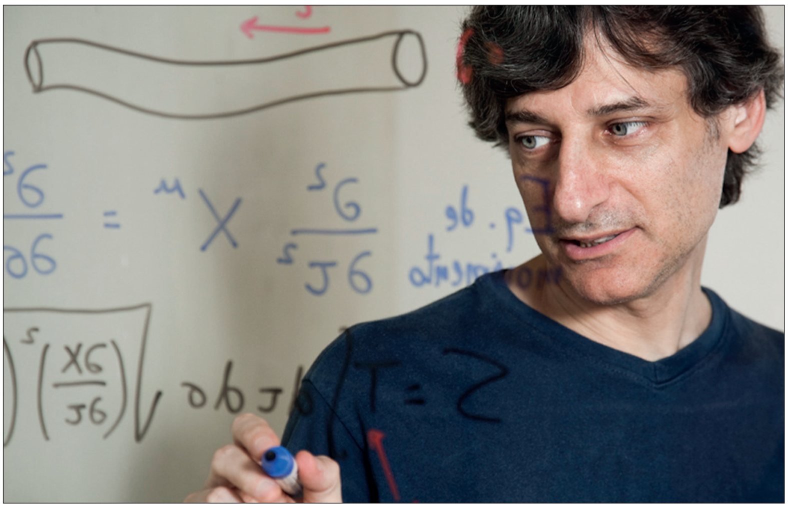
Berkovits hasn't retired from the international scene, though, and in 2012 he became the director of a new regional institute for theoretical physics that's sponsored by the International Centre for Theoretical Physics (ICTP) in Trieste, Italy, along with UNESP and the state funding agency for São Paulo, FAPESP. According to Berkovits, the ICTP South American Institute for Fundamental Research (ICTP-SAIFR) is the first in a series of local centres aimed at expanding the reach of the ICTP to emerging scientific regions (see ICTP expands in South America).

### Strength and depth

Quantum effects on a different scale dominate the work of two condensed-matter theorists at the State University of Campinas (UNICAMP). Amir Caldeira, who currently co-ordinates the National Institute of Science and Technology for Quantum Information, studies macroscopic quantum systems – such as superconducting or magnetic devices – which are small enough to display quantum behaviour but too large to be decoupled from the environment. "Physicists have been studying these systems since the mid-1980s and they have become candidates for the qubits in a quantum computer," he says. "But they must be cooled to ultralow temperatures to see any quantum effects, so they are difficult to study experimentally."

Meanwhile, Eduardo Miranda focuses on strongly correlated systems, materials in which the interactions between electrons give rise to unusual but technologically important phenomena such as superconductivity and metal-to-insulator transitions. One key focus for Miranda has been intermetallic heavy fermion systems, such as the lanthanides and actinides. At low temperatures these materials behave like normal metals, but their collective behaviour causes the electrons to act as though they are much heavier, sometimes by a factor of more than 1000. "In these complex systems the biggest challenge is often to find the most appropriate theoretical technique to study their behaviour," he says. "This area is driven by experiment, but we need a theoretical framework to understand the effects."

Theoretical models and simulations are a mainstay of many physics departments in Brazil, says Miranda, but UNICAMP is fortunate to combine its theoretical prowess with a strong tradition in experiment. "Here we have one theoretical physicist for two experimentalists, which is a healthy ratio," he says. "In Brazil, often there are more theorists because they require less funding – they only need a computer."



**Superstrings** Nathan Berkovits enjoys the freedom of academic life in Brazil.

## ICTP EXPANDS IN SOUTH AMERICA

**First of many** Physicists including ICTP director Fernando Quevedo (third from left) at the opening of the ICTP-SAIFR.

The ICTP-SAIFR has ambitious plans to become a leading international centre for theoretical physics research, and to provide scientists throughout South America with the education and skills that they need to develop a career in theoretical physics. Activities in the first year have included schools on mathematical biology, symbolic computation, and astrophysics and cosmology – this last one organized by Vanzella and Matsas – as well as workshops and mini-courses on fields as diverse as gravitational waves, high-energy physics, and quantum field theory.

In addition to these activities, the centre will initially support five permanent researchers and around a dozen post-docs. Recruitment into those positions is still continuing via an international search committee, which has the aim of hiring leading theoretical physicists from around the world.

According to Berkovits, FAPESP provides funding for graduate schools and workshops, as well as visiting professors and post-docs. UNESP covers the cost of permanent researchers and staff, while the ICTP supports visitors from other Latin American countries. "Countries such as Peru and Colombia have good undergraduate courses but not much research. We have held schools for 50–60 graduate students, of which about half come from elsewhere in Latin America."

Berkovits is confident that the centre will make a difference. "In 18 months we have achieved a lot," he says. "I think we are going in the right direction."

## Q&A: Marcia Barbosa

# Women still face 'leaky pipeline'

*Marcia Barbosa, a Brazilian physicist who is known internationally for her work to promote gender equality in science, says more women must rise to the top*

**In Europe and the US, women are well known to be under-represented in physics. What's the situation in Latin America?**
Latin American countries tend to have more women in physics, and there's two reasons why. The first is that people live closer to their families, so it is easier for women to work. The second is that, in Latin American countries, physics is not a high-ranked profession.

The universal thing is that, no matter what country or culture, there is a decrease in the percentage of women as careers advance. So if you start in a country like Brazil, there will be a maximum of 20% women at the beginning of a career, but at the top level there will be something like 5%. Depending on the country, and particularly the culture, the initial percentage might be bigger or smaller. But the universal factor is the decrease in representation. In Brazil we have five women physicists in the country at the top "1A" level. Can you imagine women entering their career now, and seeing just five women at the top?

**You've previously called this the "leaky pipeline". Where's the leak?**
At some point in her life, a woman has a kid – and then she has an option. A lot of women say, "OK, I'm just going to teach or do something else", because it's too hard to stay in physics. It's not a profession in which you can spend a year without reading any papers and then come back easily. In Brazil, a scientist is judged by the number of papers published, and no account is taken of loss of production after having a child. I'm fighting to get this changed.

**What about getting women into physics in the first place?**
There are many factors that stop girls choosing science. One is that science is not an "in thing": people prefer to be a journalist or an actor, or work on the internet. We have an image problem. In many countries this is an issue, but in Brazil it is very important for women. We are a country where how you look puts you in different levels of society, and scientists have a horrible image – and that's reinforced by the way scientists are portrayed in soap opera and other media.

As an example, when I won the L'Oréal prize most of the people who interviewed me were just mesmerised at how normal I was. "How can you be so normal?" they would say. One journalist who didn't interview me looked at my photo and said, well, she looks normal – but I bet she's completely nuts. We have to run media campaigns to change that image.

**"Can you imagine women entering their career now, and seeing just five women at the top?"**

**As you say, you won the 2012 L'Oréal–UNESCO Award for Women in Science for your research into water and protein folding. What did it mean to you?**
The L'Oréal was massive. If someone gives you a prize from an association, that's one thing. But if a fashionable company gives a prize, then you might be important. People say, "No, no, no! This is L'Oréal, that's so glamorous!" They had an expectation that I was solving wrinkle problems – even though my research is very basic, and nothing to do with cosmetics.

**And in 2009 you received the Nicholson Medal for Human Outreach for helping to establish the International Conferences on Women in Physics. What have those conferences achieved?**
We identified some key problems in each region where the conferences have been held. We went to Asia, and I must say they were thirsty for it, because they have the money and they have the resources, but they have this massive cultural background to deal with. In Japan, for example, the duties among men and women are very much split.

But there is also networking. At the 2002 conference in Paris I ended up meeting a graduate student from Germany who was stuck because she had a kid. She had to pick up her child at 5.00 p.m. every day at day care, but her professor had arranged meetings at 5.00 p.m. He couldn't understand; he thought he was being equal. So I called the German gender commission, and they convinced him that it was just a case of changing the meeting time to 3.00 p.m.

**You're a vice-president at IUPAP, an international councillor for the APS, and director of your institute. How do you find time for research?**
That is my big challenge, but I divide my day. From the morning until 2.00 p.m. I am a director. Then after 2.00 p.m. until whatever time – and I work very late – I am a researcher. I change office, and the people from the administration side know that they will have to look for me. I am always thinking, working, doing exercise. The ones who suffer are my family – they are the ones to whom I try to give quality time. But that's life. You end up accommodating.

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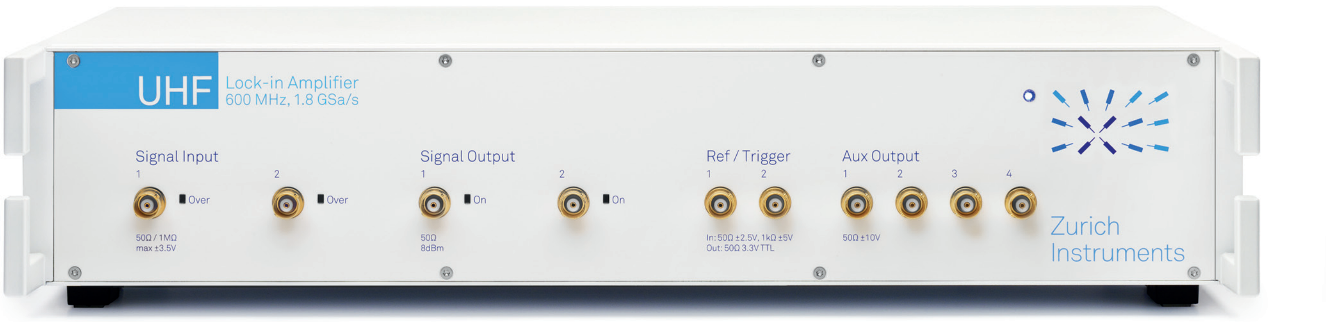


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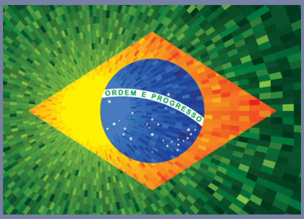


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