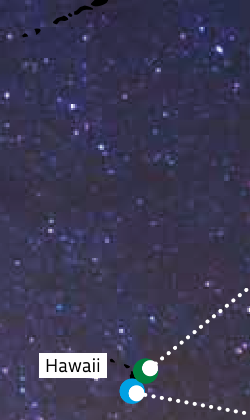

The age of grand observations

International partnerships and investments of nearly R$200 million over the next 10 years should boost astrophysics in São Paulo

Marcos Pivetta

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The São Paulo astrophysics community, which represents one-third of Brazilian researchers and one-half of Brazilian scientific production in the area, is preparing to make a qualitative leap between now and the middle of the next decade. Recent agreements with four large international groups will ensure that researchers from São Paulo will be part of the cutting-edge global work. Their ambition is to answer some of the most fundamental questions that lead astronomers to scan the skies with their telescopes, satellites and probes, such as the enigma of extraterrestrial life and the nature of dark matter and dark energy, which are two principal constituents of the Universe and about which we know almost nothing. By 2024, FAPESP will have spent almost R$200 million on these projects in addition to investments on other astrophysics initiatives.

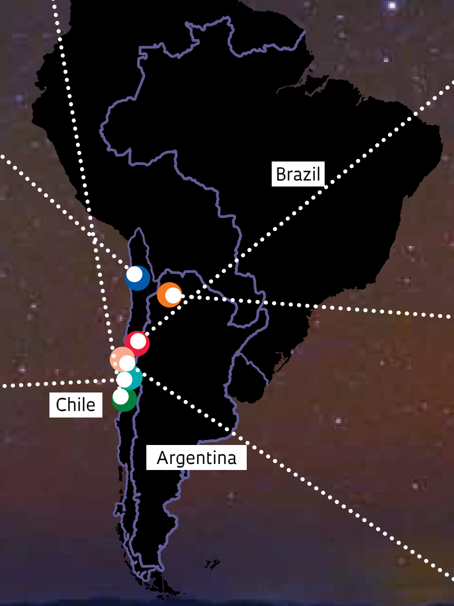
In the field of visible-light and infrared radiation observations, one of the initiatives that can expand the human view of the cosmos is the Giant Magellan Telescope (GMT), which measures 24.5 meters (m) and will be the largest land telescope when it is inaugurated, probably in 2021. Through a $40 million agreement between the Foundation and the international consortium responsible for managing the construction of the super telescope, astrophysicists from universities and institutions in São Paulo will be entitled to 4% of GMT observation time. "With this agreement, we are ensuring the future of Brazilian astrophysics and the research that we will be carrying out in 2030," says astrophysicist João Steiner of the Institute of Astronomy, Geophysics and Atmospheric Sciences of the University of São Paulo (IAG-USP), who initiated and coordinated the project that paved the way for the entry into the GMT.

Radio astronomy, a specialty that is not yet advanced in Brazil, is expected to gain impetus with the Large Latin-American Millimeter Array (LLAMA), a joint initiative of São Paulo and Argentine researchers. The acronym is a humorous reference to a member of the typical fauna of the Andes, where the 12-m diameter antenna will be installed in the first half of 2016 at an altitude of 4,800 m. "Our Itapetinga radio telescope in Atibaia is outdated and LLAMA will be important for radio astronomers because it is much more sensitive," says Jacques Lépine of IAG-USP, who is the project coordinator. The antenna can work alone or together with the Atacama Large Millimeter/Submillimeter Array (ALMA) in Chile, the largest radio astronomy project in the world.

PHOTO ESO / B. TAFRESHI INFOGRAPHIC ANA PAULA CAMPOS

Observation time

Brazil's access to international telescopes and the new projects



TELESCOPES IN OPERATION

GEMINI
Two optical telescopes each measuring 8.1 m. One is located in Hawaii, the other in Chile. Brazil has 6.2% of the total time on both telescopes

CFHT
Brazilians have up to 16 nights per year for observations on the 3.6-m telescope in Hawaii

ESO
Brazil's participation in the ESO awaits Senate approval, but the Europeans say that Brazilians can use their telescopes in Chile

SOAR
A 4.1-m optical telescope in Cerro Pachón, Chile. Since 2005, Brazil has had access to 30% of its total observation time

NEW PROJECTS

GMT
Scheduled to come on-line in 2021 in Chile. Measuring 24.5 m, it will be the first optical super telescope available for research and will produce images 10 times sharper than the Hubble telescope. Astrophysicists in São Paulo will be allowed 4% of its observation time. FAPESP is investing $40 million in a partnership with the consortium

LLAMA
As a project funded by FAPESP and Argentina, this 12-m-diameter radio telescope for millimeter to submillimeter waves will be assembled next year in the Argentine Andes. Brazil is investing approximately $9 million to purchase the antenna, and the Argentines are building the observatory

J-PAS
This project will map the Universe in 3D. The partnership between Spain and Brazil will consist of two telescopes in Teruel, Spain. One of them will have the second largest astronomical camera in the world, which will be equipped with 59 filters. A 0.8-m Brazilian telescope, which was recently installed in Chile, will assist with the survey

CTA
This international project plans to build the largest gamma ray observatory by 2020. It will consist of approximately 100 Cherenkov telescopes spread over one site in the southern hemisphere and another site in the northern hemisphere. Brazil's contribution includes the purchase of three 4-m telescopes for the CTA Mini-Array

The other two international initiatives cover different areas of research in astrophysics. The Cherenkov Telescope Array (CTA) involves a consortium of 29 countries and will include two arrays with more than 100 telescopes of three different sizes. It will be the largest ground-based observatory to study high-energy gamma rays. "The projects have a broad scientific scope and are complementary," says Elisabete de Gouveia Dal Pino of IAG-USP, one of the coordinators of the Brazilian contribution to the CTA. "For the first time in history, we will be able to make combined observations, collecting data from the entire electromagnetic spectrum: from low-frequency radio waves through the visible spectrum up to gamma rays at the high end of the spectrum."

The Javalambre Physics of the Accelerating Universe Astrophysical Survey (J-PAS) is a Spanish and Brazilian bi-national project whose objective is to produce a three-dimensional map of the distribution of matter throughout the Universe over the next five years. Brazil is funding and coordinating the construction of the second largest astronomical camera in the world, JPCam, with a resolution of 1.2 billion pixels and 59 different filters, to be installed in one of the initiative's telescopes.

"There is a pent-up demand among Brazilian astrophysicists for time on international telescopes," says Bruno Vaz Castilho, director of the National Astrophysics Laboratory (LNA). The federal institution manages the time that Brazilian researchers are allotted on the Gemini and SOAR telescopes and on the CFHT (Canada France Hawaii Telescope). In late 2010, Brazil signed a formal agreement to become a member of the European Southern Observatory (ESO), a consortium of 15 European countries that manages three astronomical observation sites in Chile. The agreement, which guarantees access to ESO facilities, awaits approval by the Brazilian Congress. ■

New eyes on the Universe

Telescopes will study dark matter, dark energy, and gamma rays and will map the cosmos in 3D

At 4,800 meters above sea level, in the Argentine region Puna de Atacama, which is a type of extension of the arid landscape of the eastern Chilean Atacama desert, the Alto Chorrillo site will contain a 12-m-diameter radio telescope known as LLAMA (Large Latin-American Millimeter Array) beginning in April 2016. Designed and implemented through a partnership between astrophysicists in the state of São Paulo and Argentina, the modern antenna is expected to begin operation and to produce scientific research in early 2017. In general terms, the agreement has established that the São Paulo researchers will buy the radio telescope (with US $9.2 million provided by FAPESP), and the Argentines will build the physical structure to house and maintain the equipment. "In principle, each country will have half of the telescope's observation time," says astrophysicist Jacques Lépine of the Institute of Astronomy, Geophysics and Atmospheric Sciences of the University of São Paulo (IAG-USP), who is a mentor of the project and Brazilian LLAMA coordinator. "But we are establishing key projects to be managed by bi-national teams." Half of the cost of the antenna has been paid for, and the remainder will be paid when the equipment is 100% operational. The Argentine part of the project is currently financed by the Secretaría de Articulación Científico Tecnológica of the Ministerio de Ciencia, Tecnología e Innovación Productiva (MINCyT).

The choice to place the antenna at this site in northeastern Argentina had two strategic motives. First, Puna de Atacama has an extremely dry climate with slightly higher annual rainfall than the nearby Atacama Desert, which is the driest place on the planet. Atmospheric water vapor is the main

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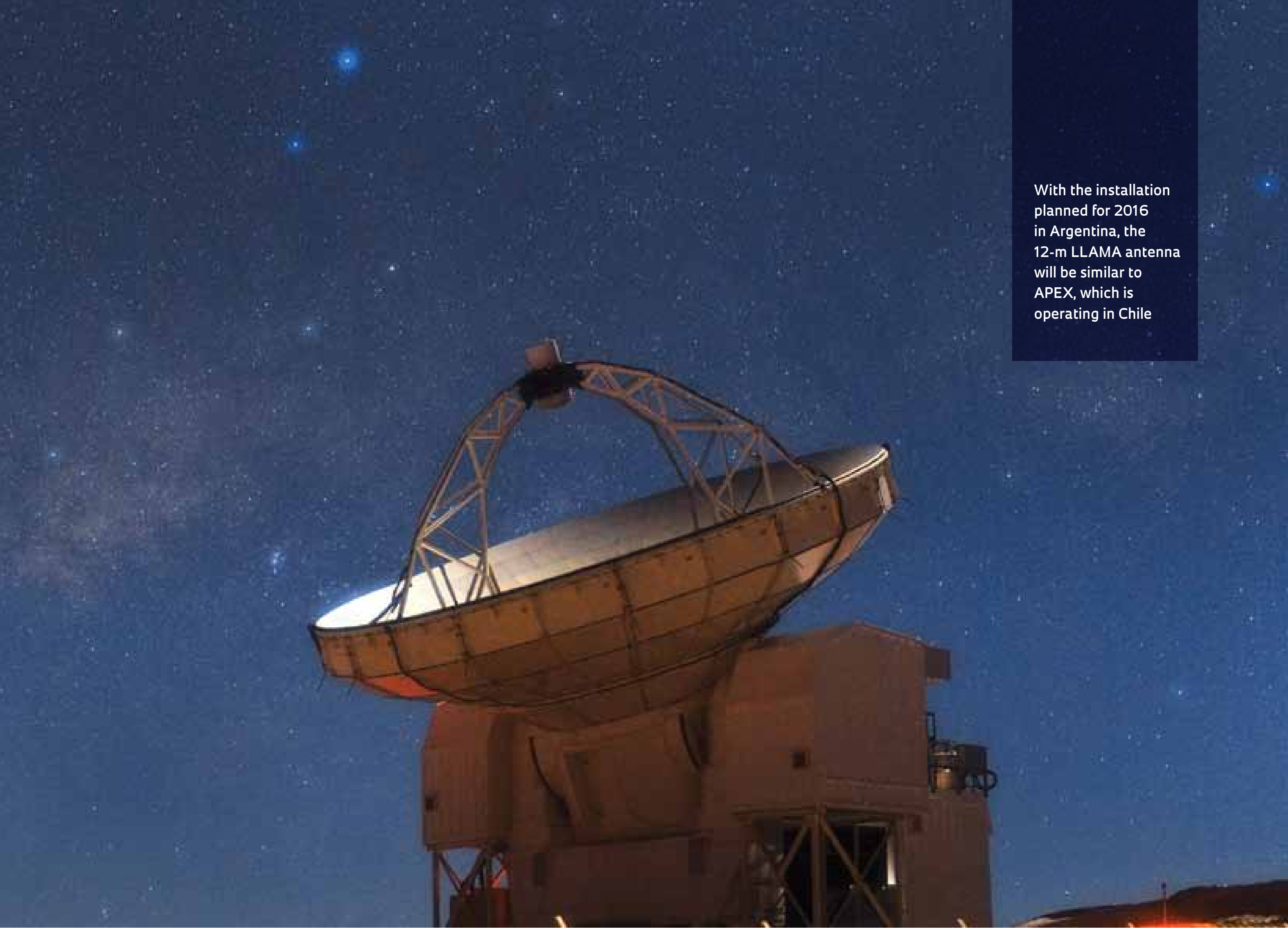

With the installation planned for 2016 in Argentina, the 12-m LLAMA antenna will be similar to APEX, which is operating in Chile

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PHOTOS 1 ESO / B. TAFRESHI 2 WWW.BRERA.INAF.IT/ASTRI

Italian prototype of the 4-m telescope for the CTA project: FAPESP is financing and building three units with the participation of Brazilian engineers

obstacle to performing good astronomical observations at millimeter and submillimeter wavelengths, such as the frequency band between 90 gigahertz (GHz) and 900 GHz where LLAMA will operate. Second, LLAMA is 150 km from the Atacama Large Millimeter/Submillimeter Array (ALMA), which is the largest radio astronomy project on the planet and located on an extremely high peak in the Chilean municipality of San Pedro de Atacama. Consisting of 66 antennas that measure 7-12 m on the Chajnantor plateau, at an altitude of approximately 5,000 m, ALMA began operations in March 2013. Near the giant radio experiment and also on the Chajnantor plateau is the Atacama Pathfinder Experiment Telescope (APEX), a 12-m radio telescope, of which LLAMA is almost a clone.

Initially, LLAMA will operate independently with no connection to ALMA. However, there is a possibility that the Brazilian-Argentine antenna can integrally work with ALMA and even APEX such that they act as a single giant radio telescope. For this purpose, the project must have an interferometry device, which combines the signals from different antennas and enables higher-resolution imaging.

LLAMA's scientific objectives include possible studies on the structure of the Sun, first stars and galaxies, emissions from jets and masers (a type of radiation similar to that of a laser) and extrasolar planets. The search for organic molecules in the cosmos is expected to be one of the first research areas to produce academic output using the antenna. Astrophysicist Sergio Pilling, the coordinator of the Astrochemistry and Astrobiology Laboratory at the Vale do Paraíba University (Univap) in São Jose dos Campos, Brazil, intends to use the radio telescope for this purpose. "With a little luck we will be able to discover molecules that have not yet been found in outer space if we look in certain radio frequencies," says Pilling.

THE UNIVERSE IN GAMMA RAYS

Another ambitious project with an international scope and involving researchers from São Paulo and other Brazilian states is the Cherenkov Telescope Array (CTA). It involves a consortium of 29 countries that plans to build the largest as-

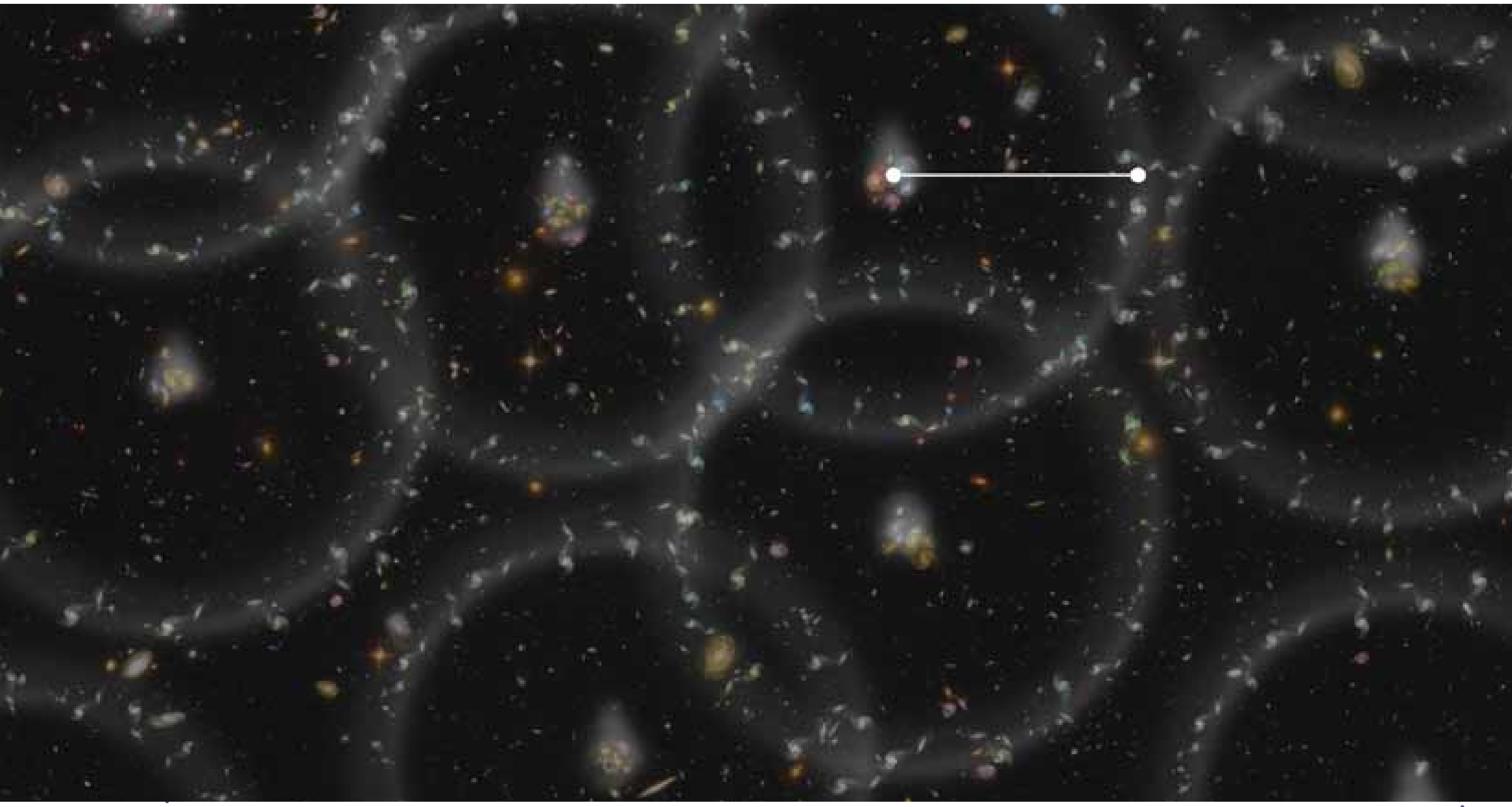

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Illustration of the acoustic oscillations of baryons

tronomical observatory for gamma rays in the world by 2020 to understand the most energetic phenomena in the Universe. Among these events are the collision of dark-matter particles; the nature of astrophysical accelerators of cosmic rays, which include colliding clouds, stars and supermassive black holes at the center of galaxies; and the violation of the constancy of the speed of light, which can only be measured using gamma rays. The observatory, with an estimated cost of €200 million, will consist of approximately 100 Cherenkov-type telescopes of three different sizes (24 m, 12 m, and 4 m in diameter), which are ideal for this type of measurement and will be distributed in two arrays. One array will be set up in the northern hemisphere in Mexico, the United States or Spain, and the other will be set up in the southern hemisphere, probably near ALMA in Chile. Most telescopes will be small. The first stage of the project, which is called the CTA Mini-Array, will set up the 4-m telescopes at the southern site by 2017.

With FAPESP funding, astrophysicist Elisabete de Gouveia Dal Pino of IAG-USP is coordinating the Brazilian contribution to the Mini-Array. At a cost of approximately €3 million, the Foundation is paying for the manufacture of three small telescopes in Italy based on a prototype. The prototype was developed by the Italian National Institute of Astrophysics with Brazilian engineers' participation. South Africa and Italy are funding another 1 and 5 units, respectively. "The Mini-Array telescopes will capture the highest energies between 0.1 and 100 TeV [100 TeV corresponds to 100 trillion electron-volts of energy]," says Pino. "They will increase the current sensitivity for capturing gamma rays by a factor of five to ten."

The Brazilian part of the initiative is not restricted to the Mini-Array. The team of Luiz Vitor de Souza Filho of the São Carlos Institute of Physics (IFSC-USP) developed the arm that positions the image camera in the CTA's midsized telescopes. He developed and tested a prototype with Orbital Engenharia, a company in São Paulo, and has now been selected to supply the structure, which measures 16 m and weighs 5 metric tons, for the other telescopes. Researchers from the Brazilian Center for Research in Physics (CBPF) and the Federal University of Rio de Janeiro (UFRJ) participated in the project and developed the 24-m telescopes.

A WIDE-ANGLE LENS IN THE SKY

With a total budget of €30 million, the Javalambre Physics of the Accelerating Universe Astrophysical Survey (J-PAS) project was originally proposed by Spain, and Brazil joined as the second partner five years ago. The initiative's goal, for which a new observatory was built in Teruel in the Spanish region of Aragon, is to produce a

PHOTOS 1 ZOSIA ROSTOMIAN, LAWRENCE BERKELEY NATIONAL LABORATORY 2 ALBERTO MOLINO three-dimensional survey of the entire sky over the next five to six years. Two telescopes, one measuring 2.5 m and the other 0.8 m, were designed for exclusive use in mapping everything from asteroids, planets and stars to hundreds of millions of galaxies in the Universe. The difference in relation to prior mappings, such as Sloan, is that the large J-PAS telescope will have the second largest astronomical camera in the world: the JPCam, which has a resolution of 1.2 billion pixels, is composed of a mosaic of 14 CCDs, and has a sensor to obtain digital images. It is a type of wide-angle lens for the cosmos.

The camera will be able to generate a record number of colors (spectra) in the images of the observed objects. It will have 59 different filters, whereas Sloan had only five, which will together generate a spectrum (set of colors) that will highlight certain characteristics of the millions of celestial bodies that will be observed. "The construction of this camera is funded and coordinated by Brazilians," says Renato Dupke, astrophysicist at the National Observatory (ON), who initiated the partnership with the Spanish. The Brazilian Innovation Agency (FINEP), Rio de Janeiro Research Foundation (FAPERJ), Ministry of Science and Technology and Innovation (MCTI), and FAPESP have invested approximately $7 million in the JPCam development, and it should be installed in the telescope in 2016. "The camera's filter system will be very useful for studying the acoustic oscillations of baryons," says Laerte Sodré of IAG-USP, another astrophysicist in the partnership. This phenomenon, which remains little understood, is characterized by waves that were created shortly after the Big Bang because of the interactions between visible (baryonic) matter and radiation. Studying these fluctuations can contribute to the understanding of dark matter and particularly dark energy, which are two main constituents of the Universe but which we know little about.

The partnership with the Spanish led astrophysicist Cláudia Mendes de Oliveira of IAG-USP to request $2 million from FAPESP to build a 0.8-m telescope identical to the smaller J-PAS equipment. The National Observatory paid R$520,000 to build the dome building and provide maintenance for the first six months of operation for the telescope, named the T-80 Sul. The equipment was installed at the Cerro Tololo site, Chile, and should come on-line in mid-2015. "We plan to carry out a survey of much of the local Universe, together with the smaller telescope in Spain, using 12 filters," explains Oliveira. "Even with fewer filters, we should be able to produce high-impact results." ■

Projects

1. *LLAMA: a mm/sub-mm radio telescope in the Andes, in collaboration with Argentina* (No. 2011/51676-9); **Grant Mechanism** Thematic Project; **Principal investigator** Jacques Lépine (USP); **Investment** R$7,890,473.28 and $9,221,992.00 (FAPESP).

2. *Investigation of high energy and plasma astrophysics phenomena: theory, numerical simulations, observations, and instrument development for the Cherenkov Telescope Array (CTA)* (No. 2013/10559-5); **Grant Mechanism** Thematic Project; **Principal Investigator** Elisabete de Gouveia Dal Pino (USP); **Investment** $2,269,594.10 and R$1,981,476.55 (FAPESP).

3. *Acquisition of a robotic telescope for the Brazilian astronomical community* (No. 2009/54202-8); **Grant Mechanism** Multi-user Equipment Program; **Principal investigator** Cláudia de Oliveira (USP); **Investment** $1,746,697.84 and R$1,325,134.14 (FAPESP).

4. *Pau-Brasil: acquisition of CCD detectors for the panoramic CCD camera of the Javalambre—physics of the accelerating Universe survey* (No. 2009/54162-6); **Grant Mechanism** Multi-user Equipment Program; **Principal investigator** Laerte Sodré (USP); **Investment** $1,600,000.00 and R$912,000.00 (FAPESP).

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New 0.8-m Brazilian telescope in Cerro Tololo, Chile: partnership with Spanish researchers on the J-PAS project