White and silver: the elegant SOAR building and its Gemini Sul neighbor, in the background

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Journey to the stars

Astronomical instruments made in Brazil equip the SOAR telescope in the Chilean Andes

Ricardo Zorzetto, from Cerro Pachón

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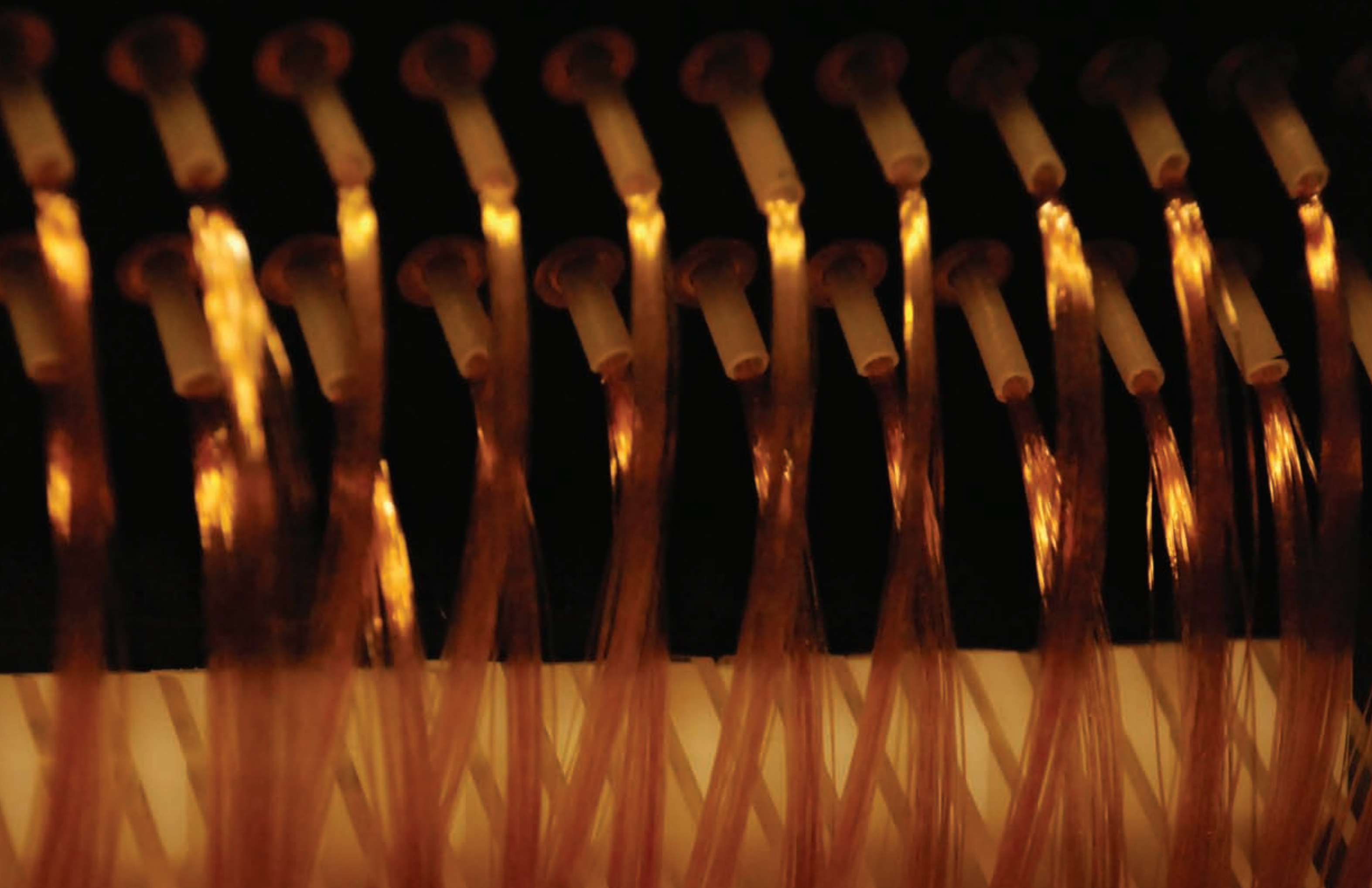
Physicist Antônio César de Oliveira barely saw the light of day in the last week in January. He, astronomer Flávio Ribeiro and mechanical engineer Fernando Santoro spent five consecutive days at the top of a bare, rocky, mountain in the Chilean Andes. They left their dormitory in the morning, traveled 3 km. on a narrow, dusty dirt road and only returned late at night, when an uncountable number of stars were already twinkling in the sky. There was little time and a lot to do. With the help of Chilean technicians they connected the biggest and most complex astronomical equipment ever made in Brazil to the telescope of the Southern Astrophysics Research Observatory (SOAR), constructed with Brazilian and North American funding, close to Vicuña, in northern Chile.

With around 3,000 parts and weighing a little more than half a ton the equipment the Brazilians installed at the end of January is a spectrograph, a device that decomposes light into the different colors (spectra) that constitute it – some of them are invisible to the human eye, like ultraviolet and infrared. Inside the spectrograph the light from close or distant stars explodes in a succession of all the colors in the rainbow, but in proportions that vary according to the chemical composition of the object observed.

The instrument installed at SOAR, however, is not just any spectrograph. The device that reached the observatory building in Cerro Pachón on December 10, after travelling 3,500 km overland from the workshops of the National Astrophysics Laboratory (LNA) in Itajubá, Minas Gerais, is a spectrograph with technological innovations that make it unique. One of the characteristics that make the SOAR Integral Field Spectrograph (SIFS) a special instrument is its capacity to fraction the



Threads of light: 1,300 fibers connect the telescope to the SIFS spectrograph

image of a heavenly body into 1,300 equal parts and in one go record the spectrum of them all. In some months, when it is working at full potential, the SIFS will allow, for example, an evaluation of the chemical composition of 1,300 points of a galaxy in one measurement that will take few minutes, a task that until now has required hundreds of different measurements.

"For astronomers that is a lot of information", explained physicist Clemens Gneiding last October during the final stage of the assembly of the SIFS in the laboratories of LNA, before embarking for Chile. And that's not all. This spectrograph was planned to have extremely high spatial resolution power. "It can distinguish objects very close in the sky, separated by 1 arc-second [a unit of angle measurement]", he added. In more concrete terms this corresponds to the size of a soccer ball seen from 50 km away – something absurdly small.

On the afternoon of January 28 the Brazilian team was running from one side to the other in the white shining SOAR building that can be seen from afar by passengers on flights that land in the region. They tried to finish the SIFS connection before the week ended. "A week is very little time to complete the installation and make the necessary adjustments", said Santoro, who is responsible for the mechanical part of the project.

"The most complicated thing is installing the cable with the optical fibers that join together the two parts of the spectrograph", commented Oliveira, while he assessed the best way to fit the 8 centimeter in diameter and 14 meter long flexible tube to the base of the telescope; this tube contains the superfine glass fibers – half the thickness of a hair – which has to conduct the light from the first to the second module of the instrument. "We have to be careful because these fibers are going to move a few centimeters to accompany the movements of the telescope, but they can't be stretched", explained the physicist, who is a specialist in optics, and coordinator of the LNA's Optical Fibers Laboratory. If the fibers are pulled taut they may break and leave the US$ 1.8 million spectrograph, financed by FAPESP, 'blind'.

With the SIFS in activity the light collected by SOAR's 4.1 meter mirror will be focused on the so-called pre-optical module of the spectrograph, a rectangular black box a little bigger that a desk-top computer, attached to the base of the telescope. Inside this module a set of lenses amplifies the intensity of the light by 10 to 20 times and reflects it onto 1,300 microlenses. Each microlens, in turn, guides the light it receives to one of the 1,300 optical fibers which, like the electricity wires in a house, conduct it to the second and bigger module of the equipment: the bench spectrograph, which installed wo meters below, in the telescope's supporting column. There, a further 18 lenses – some of them can turn up to 130 degrees with the precision of

Never resting: SOAR's instrumentation team makes adjustments to the equipment received in December

thousandths of a millimeter – either disperse, align or make the luminous beams converge until they reach the sensor where they are recorded.

The choice of such delicate and fine optical fibers was a risky bet by the Brazilian researchers. The nucleus of the fibers, through which in fact the light passes, is only 50 micrometers (thousandths of a millimeter) thick and, at the time, different research groups stated that fibers less than 100 micrometers thick would cause a loss of most of the light that should reach the second module of the spectroscope. Basing it on good results from a piece of equipment constructed in Australia, the team that planned the SIFS decided to experiment with finer fibers. But it was a well calculated risk. Before exerting a great deal of effort and investing so much money in the equipment they built a smaller version of the spectrograph in partnership with the Australians, which for two years has been functioning – and very well, as a matter of fact – in the telescope on the Pico dos Dias Observatory in Brasópolis, a town in Minas Gerais, close to Itajubá.

There were plenty of reasons to justify the investment in the innovation – one of them economic. The smaller the diameter of the fibers the closer they can be aligned where they enter the equipment's second module. As a consequence they also reduce the dimensions of the lenses and of other optical components, the price of which increases proportionally with their size. "The use of fibers with twice the diameter would make the spectrograph double in size", says astronomer Jacques Lépine, from the Institute of Astronomy, Geophysics and Atmospheric Sciences at the University of São Paulo (IAG-USP), the first coordinator of the project that developed the SIFS in partnership with Gneiding, from LNA. In the case of this spectrograph, doubling the size of the second module – an octagon 70 cm tall and 2.4 meters at its widest – would have meant making it almost as tall as a person and as wide as a good-sized bedroom in an apartment.

In the 15 meters that separate the focus of the telescope from the sensor of the spectrograph the already weak light from the stars, galaxies or planets undergoes a series of deviations and

PHOTOS RICARDO ZORZETTO

THE PROJECTS

1. Construction of two optical spectrographs for the SOAR telescope – nº 1999/03744-1
2. Steles: high resolution spectrograph for SOAR – nº 2007/02933-3
3. Evolution and activity of galaxies – nº 2000/06695-0
4. New physics in space – formation and evolution of structures in the Universe – nº 2006/56213-9

TYPE
1. Regular Aid for Research Project
2., 3. and 4. Theme Project

COORDINATORS
1. Beatriz Leonor Silveira Barbuy – IAG/USP
2. Augusto Damineli Neto – IAG/USP
3. Ronaldo Eustáquio de Souza – IAG/USP
4. Reuven Opher – IAG/USP

INVESTMENT
1. R$ 3,254,030.59 (FAPESP)
2. R$ 1,373,456.33 (FAPESP)
3. R$ 1,520,687.31 (FAPESP)
4. R$ 1,926,187.91 (FAPESP)

reflections and loses intensity; and the less intense it is the worse the definition of the spectrum produced by the equipment. The researchers reduced this loss using mirrors with a greater reflective capacity and anti-reflective coated lenses that avoid light loss. So they managed to guarantee that 80 – 85% of the light captured by the telescope would reach the SIFS sensor.

Planned a little over a decade ago the SIFS belongs to the first generation of equipment at SOAR, which will only be complete in 2011, with the installation of the fourth and last instrument that Brazil has undertaken to supply. "In creating the consortium that administers the telescope the country became responsible for producing these pieces of equipment", says Beatriz Barbuy, astrophysicist from IAG-USP and coordinator of the Thematic Project that financed the construction of the spectrograph.

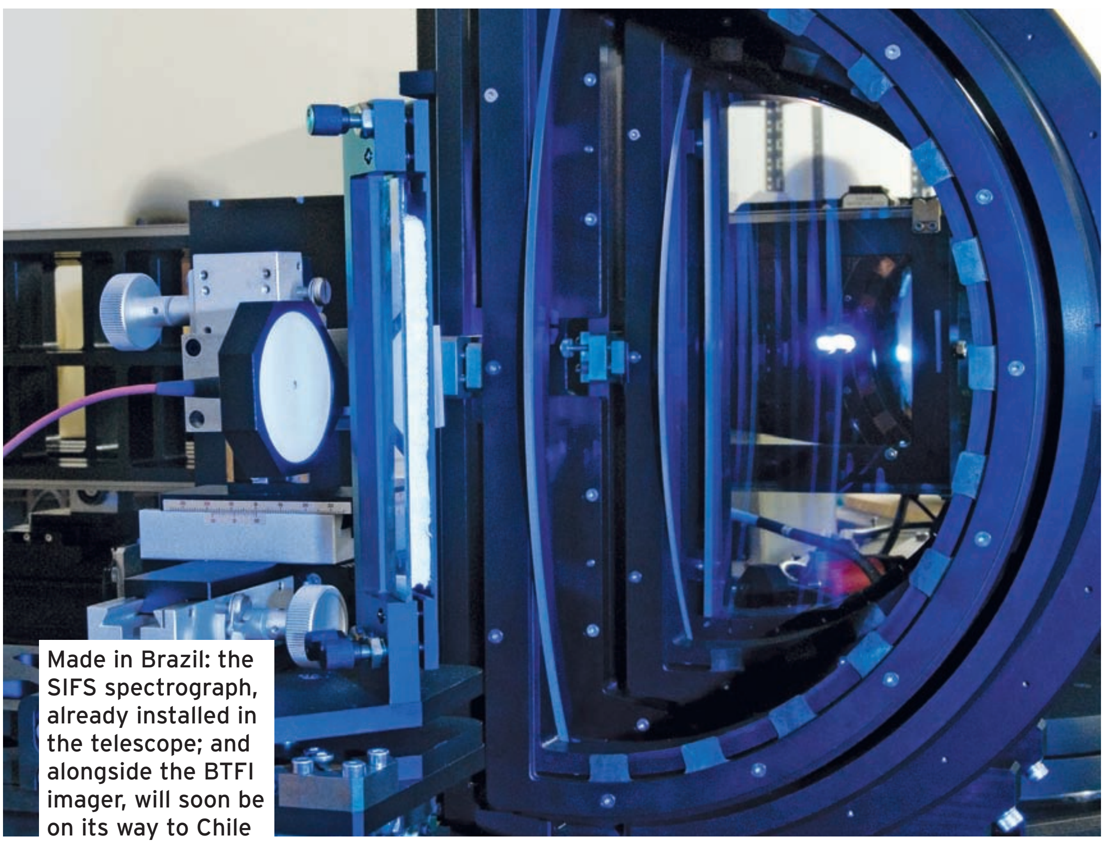
It took almost 10 years of work from the conception of the equipment to its installation, which used the labor and knowledge of at least 20 researchers and highly specialist technicians. Execution of the project also demanded the formation of a not-so-frequent partnership in Brazil, between universities, research institutes and private companies.

> **"First generation equipment will only be ready in 2011, with the installation of the fourth and last instrument that the country undertook to supply for the telescope**

"In Brazil there was no culture and expertise for producing such a large piece of astronomical equipment", comments Keith Taylor, the English astrophysicist who coordinated the optical group of the Anglo-Australian Observatory in Australia and who for two years has been managing the development of SOAR's instruments.

The researchers say that it would have taken much less time to produce the SIFS if they had had easier access to the materials, which needed to be imported. Part of the delay was due to complications in the importing of parts, like calcium fluoride lenses supplied by North American company, Harold Johnson, which took nine months to reach Brazil, and the optical fibers bought from Polymicro Technologies, also in the United States.

In mid-2009, a few months before the SIFS was sent to Chile, another piece



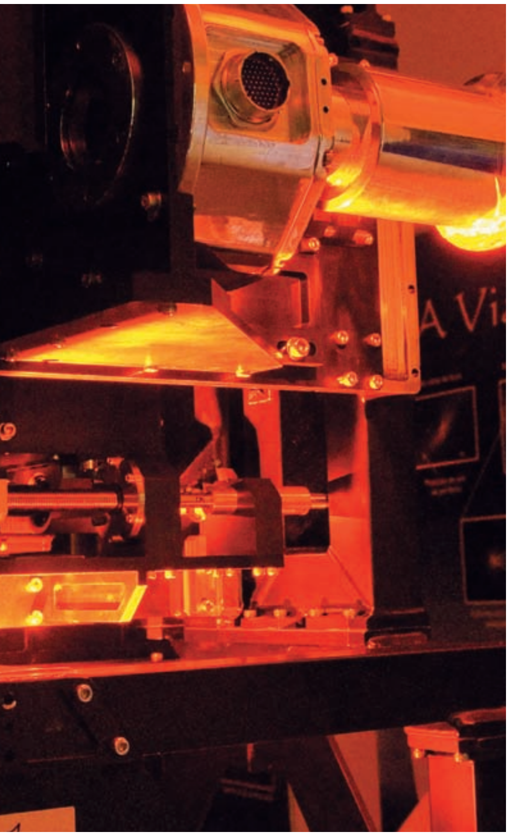
Made in Brazil: the SIFS spectrograph, already installed in the telescope; and alongside the BTFI imager, will soon be on its way to Chile of equipment, planned and constructed with the participation of Brazilians, had been connected to the SOAR: the Spartan camera, which specializes in producing images in infrared – a form of electromagnetic radiation perceived by human beings as heat and capable of crossing the gigantic interstellar dust clouds that hide the galaxies and the nurseries of the stars. As part of the first group of instruments manufactured specifically for this telescope, the Spartan substituted a camera on loan from the Blanco telescope of the Cerro Tololo Interamerican Observatory, located 10 km to the northwest of SOAR on one of the countless reddish peaks on the mountain range.

Almost 8 years ago, astronomer Sueli Viegas, an USP retiree, started a project in cooperation with the University of Michigan, in the United States that led to development of the Spartan. "Brazil participated in preparing the optical and mechanical project for this camera and bought two of the four infrared detectors", says Ronaldo de Souza, an astronomer from the IAG, who took over coordination of the project after Sueli moved to the United States.

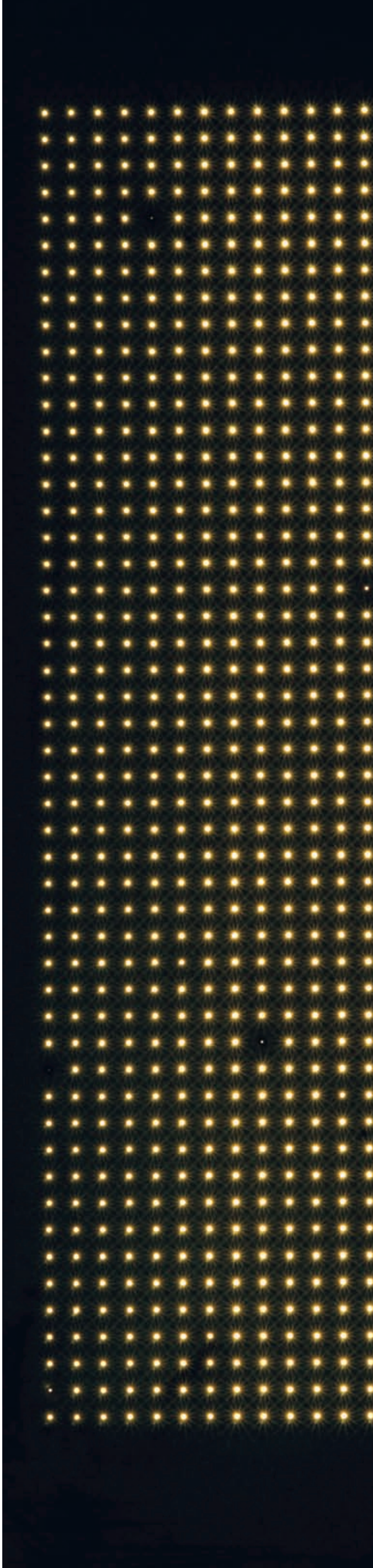
The two detectors alone cost almost US$ 700,000, half paid with money from the Sueli Viegas project and half with funds from the Millennium Institute, coordinated by Beatriz Barbuy, from the IAG-USP, and Miriani Pastoriza, from the Federal University of Rio Grande do Sul. Since September, 2009, the Spartan has been functioning experimentally. In this phase, the astronomers are learning to deal with the equipment, which may still undergo adjustments and there is no guarantee that the observations will be very accurate. "SOAR was planned to present high performance, with equipment of the highest optical quality", says Keith Taylor.

A little more than five months after the conclusion of the building and assembly of the telescope, SOAR is coming to life and becoming independent. It is planned to deliver the Brazilian Tunable Filter Imager (BTFI), equipment that costs US$ 2.2 million and that will allow for identification of the chemical composition of these celestial objects and for measurement of their relative internal movements. "This instrument will be attached to a module that corrects the effects of turbulence in the atmosphere", says Claudia Mendes de Oliveira, from USP. "Allied to the quality of the image from the BTFI, this correction will result in images of unprecedented sharpness, giving SOAR the capacity that other telescopes of the same size do not have", says the astrophysicist who coordinated the teams from Brazil, France and Canada that constructed the BTFI.

"The production of these instruments inaugurated a new era in Brazil-



PHOTOS EDUARDO CESAR



Side by side: arrangement of optical fibers demanded precision and a lot of patience

The birth of a telescope

In 1998, two years after the project was approved, the building work started with an explosion on the summit of Cerro Pachón, in Vicuña, in northern Chile, and the extraction of 13,000 m³ of rock to create a flat area for the headquarters of SOAR

A year later the building that will house the telescope and the control room began to take shape, built on a piece of land 2,701 meters above sea level and 80 km from the Pacific

In the 2002 the building received the 14-meter metal dome made by Equatorial, from São José dos Campos, in São Paulo State, which protects the telescope when night time humidity increases

The 4.1-meter mirror and light-capturing power, 350,000 times greater than that of the human eye, reached SOAR in January 2004, after traveling almost 10,000 km from the place it was built in the United States

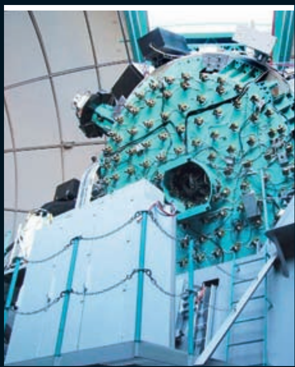
ian astronomy and boosted national astronomical instrumentation", says Beatriz Barbuy. These expensive devices, devised with the objective of expanding human comprehension of the Universe, consume a large number of very small parts that fit together and move with extremely high precision. "Just for the BTFI, we supplied some 1,500 parts", says Paulo Silvano Cardoso, director of the optomechnical material company, Metal Card, from São José dos Campos, in São Paulo State.

"In 10 years, Brazil has managed to establish an international level instrumentation program", says João Steiner, the astrophysicist from the IAG-USP who was a member of the management board of SOAR for 12 years and took part in the telescope project right from its conception in 1993 (*see* Pesquisa FAPESP *nº 98*). He says that Brazilian researchers even tried to begin producing astronomical instruments years ago when the country was first part of the Gemini Observatory consortium, which has two telescopes with 8.2-meter diameter mirrors, one installed in Hawaii and the other, 350 meters from SOAR, on the Cerro Pachón, 2,701 meters above sea-level. But the project never got off the ground. "It was too big a step", explains Steiner, who even ended up in hospital because of the stress levels during construction of the telescope.

By the start of 2011 a fourth instrument should be ready: the *échelle* spectrograph of the SOAR telescope (Steles), which the team of astronomer Bruno Vaz Castilho is currently building in LNA's laboratories. Similar to SIFS, the spectroscope that the Brazilians installed in January in the building at Cerro Pachón, the Steles, will also analyze the colors of light emitted by stars and galaxies. The difference is that it will see a greater pro-

> **"In ten years Brazil managed to establish an international level astronomical instrumentation program, with benefits also for industry**

PHOTOS SOAR/LNA/MCT



On the night of April 17, 2004 the telescope made its first observation or, as astronomers say, saw its first light, still using equipment on loan from other observatories

portion of the spectrum of visible light – and with better resolution. The use of two instruments from the same family may seem redundant, but it is not. Each one has specific applications. While the SIFS generates 1,300 spectra in a single exposure, Steles produces just one. "As the Steles will record the whole of the visible light spectrum in one go it'll allow us to analyze different characteristics of the object observed, such as its chemical composition, temperature, speed of rotation or the speed at which it is moving away", says Castilho.

"When these pieces of equipment have been delivered the first and second generation of instruments defined in the initial project will be complete", says Alberto Rodriguez Ardila, national manager of the SOAR. This does not mean, however, that the telescope will be fully equipped. "Scientific advance always generates the need to develop new instruments", he says. In the opinion of this astrophysicist from LNA, the result of so much work should be noticed in a few years time in the scientific projects that will be developed at the SOAR. "The use of these instruments is likely to increase the dispute for observation time and improve the quality of research", says Ardila.

Before its own set of equipment had even arrived the white telescope at Cerro Pachón was not idle. Since it received the first light from a star in 2004 until December last year, the SOAR has been responsible for generating 36 scientific articles that have been published in international periodicals. Nineteen of the articles (53%) were produced by Brazilian researchers, who have only 34% of the telescope's observation time.

But recognition from the international scientific community really came about in 2007, when the result of an observation made at SOAR by a Brazilian was published in the coveted pages of the journal, *Nature*. Almost two years before, in the early hours of the morning of September 25, 2004, the space observatory Swift, from the North American Space Agency (Nasa), issued a warning with the coordinates of what could be an explosion of gamma rays – the death of a star, the mass of which was dozens of times greater than the Sun, which is transformed into a black hole, one of the most energetic events known to man – that had occurred within the Pisces constellation (*see* Pesquisa FAPESP *nº 116*). Eduardo Cypriano, one of the first resident astronomers at SOAR, a type of telescope 'tamer', was working that night and detected the first signals from the explosion.

At the request of Daniel Reichart, a North American academic who studies these phenomena, Cypriano pointed his telescope at the same point in the sky for a few more days. A week later came the official announcement: the images taken by Cypriano and analyzed with the help of his wife, astronomer Elysandra Figueredo, had captured the explosion of a star 12.7 billion light years away from Earth. SOAR had been the only telescope on the planet to accompany this rare phenomenon, which was later confirmed by other observatories. "It was the most distant and oldest object so far observed at that time", says Cypriano, who believes that as soon as the adjustments have been finalized in the SOAR equipment Brazilian astronomers will be well served for at least a decade.

While they await the conclusion of the last pieces of equipment – SOAR has eight pieces in all –, the Brazilians are planning the next steps. A group coordinated by João Steiner and Beatriz Barbuy is assessing the possible participation of Brazil in the next generation of telescopes. These are grandiose projects that are likely to cost between US$ 700 million to US$ 1.4 billion to erect telescopes with a mirror up to 40 meters in diameter, four times bigger than the biggest telescopes now in use. In comparison SOAR cost US$ 28 million, of which US$ 14 million was paid by Brazil, divided between the National Council for Scientific and Technological development (US$ 12 million) and FAPESP (US$ 2 million).

Entering astronomy's first division, however, is not cheap. Brazil is negotiating to pay 10% of the total amount to have access to the Thirty Meter Telescope, with a 30 meter mirror, or 5% to have the right to use the Giant Magellan Telescope or the European Extremely Large Telescope, of 22 meters and 42 meters, respectively. But it is demanding a counterpart. "We'll not go into any project unless at least 70% of these funds are earmarked for manufacturing of the equipment by Brazilian industry", says Steiner.

The astronomers have at least two good reasons for justifying such a large investment. The first and more abstract: access to these mega telescopes will guarantee Brazilian researchers at least the chance to look increasingly further into the Universe in their search for convincing answers to one of the simplest and most fundamental of questions that any human being ever posed: how did it all begin? The second is more pragmatic: Brazilian astronomy, a young area that grew very quickly in the 1990s, cannot stagnate if it wants to remain internationally competitive. "If we stop", says Steiner, "we'll condemn the next generation of astronomers to remaining outside cutting edge research as from 2025. We'd be the only emerging country to do so". ■