SPACE SCIENCES IN LATIN AMERICA[1]

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Introduction

For institutions and individuals managing the funding and formulation of development strategies and priorities, basic space sciences is perhaps one of the most difficult areas to tackle. On one hand space sciences, both basic and applied, promise to be of great potential for applications that are urgently needed in developing countries. Monitoring of land use and atmospheric conditions, telecommunications, remote sensing applications, etc are only a few of the areas in need of expertise and participation in developing countries. On the other hand, space technology is by its nature an expensive endeavor which on the face of competing priorities in countries with seemingly insurmountable budgetary constraints, becomes relegated to the category of luxurious activities. For the scientist interested in developing space sciences, his/her task becomes even more difficult because given the very well known obstacles that scientists have to face in developing countries one finds that the activities of space scientists, often times, are considered 'out of place' even

[1]in *Developing Basic Space Science World-Wide*, Ed. H.M. Haubold (UN), W. Wamsteker (ESA) and R. Albrecht (ESO)

by their fellow scientists working on other fields. It is not uncommon for scientists from developing countries to express that the 'useful' sciences should be funded and practiced in their countries and the 'not-so-useful' sciences should be left for the developed countries. Space scientists in particular face this mentality and thus the concern for survival becomes imminent. What can be done to change this situation? Is there any hope for developing countries to see a consolidated scientific space community capable of generating and using its own technology one day?

The term 'basic space sciences' is used here to refer to research related to observations of the celestial sphere in the full range of the electromagnetic spectrum. This broad definition includes the areas of astronomy, astrophysics, cosmic rays, cosmology, solar-terrestrial interactions, and planetary and atmospheric studies.

Basic space sciences in developing countries share with the other scientific fields similar problems. However, in space sciences the known difficulties become amplified due to the fact that space and the stars are seen as a subject too remote to be considered by policy makers pressed to find rapid solutions to their country's problems. Thus, a close examination of the issues involved in developing space sciences in developing countries serves as evidence of the problems that all our scientists are facing. Possible solutions, recommendations and strategies emanating from this exercise will also apply to other fields in basic sciences.

The problems that most afflict the development of space sciences in poor countries are well known and pose the hardest challenge for scientists and policy makers as well. Insufficient capital, lack of a scientific tradition, brain drain, lack of governmental support, inadequate infrastructure, competition, and an ever more growing gap with developed nations, have been the conditions of these countries. As a consequence of the bleak panorama that we observe, scientists have inherited an immense responsibility and their task has increased to also include lobbing, policymaking, and outreach activities.

A review of past experiences and the current status of space research activities on the part of developing countries reveals that the strategy to follow is one in which the initiative of individuals to start research activities must be complemented with a coordinated plan at the national and international level. One could differentiate two models of development: the first in which the actions of a small group of individuals driven by a common scientific interest results in the formation of collaborations towards the achievement of very specific goals (the 'bottom-up' model). The second consists of projects that can be conducted only as a result of international agreements and development plans that need governmental support (the 'top-down' model). The right solution, as argued here, is a judicious combination of both strategies.

An exhaustive review of the status of basic space sciences in developing countries is a daunting task that is not the scope of this article. However, one can single out few examples to illustrate the virtues and difficulties with the two development strategies mentioned above (for a complete treatment of the subject the reader is referred to the proceedings of UNISPACE 82, Chipman 1982).

The Scientific Development of Latin American Countries

Based on science development indicators space sciences in Latin America (LA) follow the same pattern as research and development (R&D) in general. It is therefore instructive to review the current status and trends of science in LA countries. This review relies on the input and output indicators commonly used to evaluate scientific development: gross expenditure on R&D (GERD), personnel working in R&D, and bibliometric data. The sources used to elaborate this review are primarily the UNESCO report (see UNESCO 2001), the National Science Foundation (see NSF 2002), the Ibero-American Network on Science and Technology Indicators (see RICYT 2003), and the Institute of Scientific Information (see ISI 2003).

A note about indicators: the above-mentioned science indicators have limitations and are subject to bias. By any means it is claimed here that the state of scientific development of a whole nation can be encapsulated in such a simplistic set of metrics. They are however useful to indicate the relative development among countries. In absolute terms it does not make sense to compare for instance the science budget of a poor LA country with that of the US. Beyond the obvious disparity little insight can be gained from such exercise. In the analysis below, absolute comparisons have been used only to contrast and to put into context some of the indicators. By using the US to compare indices it is not suggested that the US is the best model for developing countries to follow. Also, when interpreting relative indices (i.e. GERD relative to gross domestic product (GDP) or number of publications relative to number of researchers) much caution must be used, as results could be misleading. Take the case for instance of a very poor country with GERD below the mean for its group and a number of researchers not exceeding few tens (not an untypical situation). Lets assume that the country in question has a very prolific researcher producing tens of publications a year (not untypical either). The number of publications per researcher in that country could surpass developed countries by a large margin. This result of course has nothing to do with the country as a whole. Notwithstanding the aforementioned shortcomings, lets take a look at what can be discern about the state of science in LA.

A most striking characteristic of the scientific development of LA countries is the vast disparity of development among its member nations. The level of development goes from countries where the existing infrastructure is negligible, the poverty level is alarmingly high, and the investment in R&D is minimal (in some of these countries the total R&D budget does not buy a fraction of a research telescope) to countries such as Brazil which have developed and launched their own satellites. This state of affairs is revealed by the large variance in the scientific indicators for the whole region and for this reason it is best to divide the LA countries in separate groups based on the level of scientific development based on the metrics mentioned above.

Latin America (excluding the Caribbean countries) is made of 24 countries with a total population exceeding 500 million people and a geographic area of more than 20 million square kilometers. LA countries can be grouped in three clear levels of scientific development. The first group (G1) made by Argentina, Brazil and Mexico is the most advanced. In these countries scientific research is well established, research groups have been consolidated, the number of researchers is greater than 25,000 and the GERD has consistently been in the range US$ 1 - 4 billion per year, publication levels have over passed the 2,000 publications per year mark. Brazil, Mexico, and Argentina have respectively about 3000, 2200 and 2000 PhDs involved in physics research (Moran-Lopez 2000). A second group (G2) made by Chile, Colombia, Cuba and Venezuela has a more recent growth in researchers and R&D spending. Countries in this group have a population of researchers in the range 5,000 to 7,000; 100 to 500 physics PhDs; a GERD of US$ 100 - 400 million per year and publication levels averaging 400 per year. The remaining LA countries (Belize, Bolivia, Costa Rica, Dominican Republic, Ecuador, El Salvador, French Guiana, Guatemala, Guyana, Haiti, Honduras, Nicaragua, Panama, Paraguay, Peru, Suriname, and Uruguay) belong to the third group (G3). In the latter group the level of development ranges from countries that do not even appear in the radar screen of scientific development to countries like Panama, El Salvador, and Costa Rica, where small research groups have been formed in the last decade.

Unlike industrialized countries where the investment money in R&D is provided mostly by private industry (in the US 68.4% or US$ 181 billion of R&D funding for 2000) in LA countries R&D funding originates almost in its entirety from government sources which are overwhelmed by other urgent needs and by outside pressures to adjust budgets and to re-pay foreign debts.

In absolute terms the combined GERD of all LA countries was US$ 9.4 billion in 2000. In the same year the United States alone spent 28 times that sum in R&D. Of all the GERD in LA it is in G1 countries where most of this spending takes place (86.1%) while for G2 countries it is 12% and for the G3 group it is only 1.9%. Brazil by far is the LA country with the highest GERD (US$ 3.5 billion in 2000) by contrast the average GERD of G2 countries is US$ 280 million and US$ 22 million for G3 countries. The combined expenditure in R&D of the 17 countries in the G3 group is comparable to the cost of a single telescope, the Gemini South telescope installed in Chile. The R&D expenditure of the US in 2000 was 12,200 times larger than the average GERD of G3 countries the same year. The wide gap between the less developed and more advanced countries in LA is clearly evident. The trends in spending during the decade of the 90s are favorable for the whole region (a 53.6% increase) with G2 countries seeing the largest increase (80%). This trend has reverse course in the last 3 years. Because of budgetary mechanics the practice in most countries is to allocate R&D budgets based on a percent of GDP level, however GDP growth has been dismal or negative in some cases. The distribution of R&D budget by discipline for LA countries shows an allocation to exact sciences of 27% in average with a minimum of 7% (Mexico) to a maximum of 36% (Panama).

Among LA countries the difference in GERD relative to GDP is not nearly as large as the difference in absolute expenditure numbers. The GERD relative to GDP of the country was in average (2000) 0.58%, 0.40% and 0.20% for G1, G2 and G3 respectively (The US GERD was 2.66% in 2000). In many of the LA nations R&D spending has not been growing in proportion to the GDP. In Bolivia, Chile, Colombia, Ecuador, Panama, and Uruguay the R&D budget relative to the GDP has decreased in the period 1996-2000, and in other countries where the relative GERD has increased the actual dollar amount of R&D investment has decreased due to an overall decline in the economy of these countries.

Has the investment in R&D produced results? Lets look at the output indicators: number of researchers and publications. Of the 142,000 researchers in Latin America (as of 2000) 78.4% are from the G1 group, 15.7% from G2 and the remaining 5.9 % from G3 countries. The US has 13.7 times more researchers than all of the LA countries combined. The country with the largest number of researchers per capita is Argentina with 713 per million, the average number of researchers per million population by group is 420 for G1, 286 for G2 and 170 for G3. To contrast these numbers, the researchers in the US are 52 times the average number of researchers in G1 countries, 350 in G2 and 1,635 times in G3 countries. Trends of number of researchers since 1996 show a positive growth for all LA countries (2.4%) except for Bolivia, Ecuador, and Peru where researcher population has decreased. The G2 group saw the largest increase (4.5%) while the G3 the smallest (0.3%). Colombia shows the largest percent increase (20.7%) in the number of researchers during this period. With 5,163 graduate scholarship recipients during the 1996-2000 period Colombia also shows a strong emphasis in investment in education of researchers.

The number of publications is another indicator commonly used to measure scientific output. The primary source for this metric is the Science Citation Index (managed by ISI) who compiles bibliographic information. From the more than 70,000 scientific journals that are published worldwide only roughly 3,300 make it to the SCI. Only journals (mostly in English language) that follow a strict set of criteria are accepted to the SCI, which highlights the potential bias against developing countries resulting from a count of publications on SCI journals when it is known that many researchers in those countries publish their work in non-SCI journals (Gibbs 1995). A comparison of the number of publications by country derived from ISI data with those published by UNESCO (which uses many other bibliographic databases) reveals a consistent underestimation by a factor of 2 for the ISI numbers for developing countries (however in relative terms the bibliographic ISI and UNESCO indicators seem to scale, thus retaining the relative weight).

Of all the scientific publications in the world in 1999 2.26% came from LA countries. If one uses the number of publications as a proxy to measure scientific production it is then possible to say that the production of science results from LA countries is only 2.26% of the world production. Although a small proportion, it is nevertheless an encouraging indicator since the number of publications from LA more than double in the last decade. It was 1.18% in 1986. However it is also important to note that these results comes mostly from the G1 group which accounts for 82% of all the LA publications. The contribution of G2 and G3 countries to the LA publications is 14.5% and 3.5% respectively.

Another encouraging trend is that the total number of publications per researcher in LA is comparable with that of developed countries. This indicator has been used as a measure of relative performance (May 1997). While in the US the ratio of publications per 100 researchers per year is 8.4 in LA the same number is 8.3 and some countries have publications per researcher larger than the US: Brazil 10.3 and Chile 12.2 (these figures are derived from ISI 1999 data, when using UNESCO and RICYT numbers the results are consistently higher by a factor of 2). By G1, G2 and G3 the numbers are 8.6, 7.4 and 3.6 respectively.

Astronomy and Astrophysics in Latin America

Astronomy and astrophysics has been an important area of research in Latin America and an activity with deep roots in Central and South America (Sahade 1990). Brazil and Argentina have developed space technology to levels comparable with industrialized countries and Chile is host of an array of the best astronomical observatories in the world. Local scientists, however, have been only marginally involved with those large facilities. Only recently Chile has passed a law demanding access to 10%

of time to all international telescopes in Chilean territory. Chile has insufficient number of astronomers to fill in this time at the moment but the measure will surely strengthen the local scientific community.

In the region physicists have been an important group in establishing research activities (Moran-Lopez 2000). Most of the countries in groups G1 and G2 have physical societies that have helped foster academic activities. The Argentine Association of Physics was founded in 1944 and the Mexican Physical Society in 1950. Undergraduate programs in physics first appeared in the 1940s, starting with Mexico, Argentina and Brazil and graduate programs appeared only in the 1950s. Doctoral programs in astronomy are offered only in Argentina, Brazil, and Mexico. The National University in Colombia offers PhD degree in physics and Master degree in Astronomy, coordinated by the National Observatory.

The G1, G2 and G3 country classification applied to science in general is also valid for basic space sciences (with the exception perhaps of Chile where the strength of astronomy relative to the other sciences is higher than in other countries).

An indicator that reflects the relative importance of astronomy and astrophysics in Latin America is the membership in international space science organizations. Of the Latin American countries only Argentina, Brazil and Mexico are members of COSPAR (Committee for Space Research). The membership to the International Astronomical Union (IAU) is shown in the table below.

In terms of scientific production, how basic space science fares in Latin America? To get an idea of the relative strength of research in space sciences one can look at the total number of publications on these subjects and compare with the total number of publications in all fields of research. The astro-ph archive (see astro-ph reference) is a good tool to achieve this measurement. The on-line astro-ph archive is the preferred means by researchers of making manuscripts of articles available to a large audience before the article is actually published. There are obvious shortcomings (some astro-ph articles are not published at all, or published in non indexed journals, etc) nevertheless it is a useful metric to evaluate the relative strengths in space sciences research among countries because it is expected that the number of papers submitted to astro-ph is correlated with the research activity in the subject. Of all the astro-ph papers coming from LA countries (at least one author

Table 1: IAU Membership

Country	Year	Members
Brazil	1961	125
Argentina	1927	101
Mexico	1921	90
Chile	1957	46
Venezuela	1953	13
Cuba	2000	5
Uruguay	1970	3
Central America	1998	2
Bolivia	1997	0
Peru	1988	1
Colombia	1967	1
Ecuador	not member	1
Paraguay	not member	1

from an institution in Latin America) 70.3% originated in G1 countries, 28.7% from G2 countries and 1% from G3 countries. Relative to the total number of publications of the country Chile has the largest proportion of space science papers with 2.8%, followed by Mexico with 2% and Brazil with 0.7%. The latter results are underestimated as a result of astro-ph not being able to capture all of the basic space science papers. A study by SRI International (Ailes 1988) based on publication trends finds that for LA as a whole, astronomy represents 3.4 percent of its total active research areas, which is above the US or world average. The same study points out that the weight of astronomy with respect to other areas of research is very high for Chile (9.9%), following Mexico (4.3%) and Brazil (3.5%). The difference of the astro-ph derived numbers and the SRI study results can be accounted for by the reasons stated above (underestimation of astro-ph numbers) and the fact that since the SRI study (1988) the relative contribution to publications coming from other disciplines has increased.

Regional Projects

There are a large number of successful projects that started as a small group's initiative. The local presence of a strong research team is a driving force and an important element in the establishment of research groups in developing countries. The impact to the advancement of the local scientific community in Bolivia and Argentina as a result of the installation of the Chacaltaya cosmic ray station in Bolivia and the cosmic ray laboratories in Argentina are two clear examples. The case of Argentina and Bolivia help to stress once more the importance of looking at the geographic attributes in order to attract international collaborators. Astronomical observations of variable starts and gamma ray burst afterglows, environmental and bio-diversity studies, environmental geochemistry, solar physics, physics of the upper atmosphere, ionospheric physics, galactic studies, the south atlantic anomaly, equatorial electrojets, the ozone hole, cosmic ray muon neutrinos, etc are examples of subjects with special geographic requirements that developing countries can offer (Hoeneissen et. al. 1992). However, geographic attributes alone are not enough. The presence of international researchers without a local educated scientific community ready to absorb and participate will not represent benefit to the region. On the contrary, a strong local group could attract mutually beneficial collaborations with the international community. The case of the cosmic ray group in Argentina formed in 1949 around the activities promoted by Estrella Mathov and Juan Roeder is an illuminating example (Roeder 2003). This group attracted the attention of the scientific luminaries conducting cosmic ray research in Europe at the time, which resulted in a collaboration from which fundamental contributions to the field were made. Today Argentina is the host of the Auger project, the largest and one of the most important cosmic ray experiments done thus far.

Several international scientific organizations have flourished in Latin America that have accelerated the consolidation of research groups in the region by promoting and providing efficient contacts with the international scientific community. The Latin American Center for Physics (CLAF) founded in 1962 in Brazil has organized workshops and scholarship programs. The Centro Internacional de Física (CIF) in Colombia founded in 1985 has promoted the formation of research groups with the participation of countries in the region and scientists from developed countries. The areas of research most developed by CIF are biophysics, high-energy physics, astrophysics, optoelectronics, microprocessors, and biotechnology. FELASOFI, the Federation of Latin American Physical Societies founded in 1984 promotes scientific exchange among Latin American physicists. The Society of Latin American Experts in Remote Sensing (SELPER) with basis currently in Argentina and rotating among its members countries coordinates workshops and other activities for experts in the subject.

The leading role of an international organization such as the United Nations (UN) is a key factor in the coordination and the formation of international collaborations tending to open space activities by developing countries. Given the economic and social pressures that these countries have to deal with, it is almost inconceivable that one single country can afford to develop its own space technology (this fact applies to industrialized countries as well). An international coordinated effort by a large group of developing countries, however, can result in a successful space mission. This is where the actions of the UN and other international bodies can have a decisive impact. In 1958 the UN formally recognized the need and the potential for international cooperation in the field of space sciences thus establishing the ad hoc Committee on the Peaceful Uses of Outer Space (COPUOS). In 1991 the UN, in cooperation with the European Space Agency, began a program to provide basic space science education for the benefit of developing countries (Haubold et al. 1995). As a result of this program a series of Basic Space Science Workshops have taken place. Three of the Workshops have been in the LA region: Costa Rica and Colombia (1992), Honduras (1997) and Argentina (2002). The UN/ESA Workshops on basic space sciences are held in developing countries and their format is designed so that besides scientific talks of very high quality there is ample time for discussions on the main issues faced by scientists from the region. The interaction of scientists from the region with their peers in more scientifically advanced countries results in the identification of key problems and recommendations that should be adopted to ameliorate the situation. A conclusion that has came out of these workshops is that even though the different regions do not share the same conditions and level of development, there are similar problems faced by the scientists of developing countries. Due to this fact, the recommendations emanating from discussions of scientists from the different regions where the UN/ESA Workshops have taken place apply in general equally well to all of the regions. It has been recommended, for example, to build first- rate educational and research capabilities for internationally recognized scientific research by building the necessary computational infrastructure to allow access and use of space- science data archives. The participants of the Workshops recognized the need to establish local electronic communications and access to the international computer networks. The possibilities of exploiting local and geographic attributes such as latitude, high peaks, climate and bio-diversity, has also been pointed out as an important element of great potential.

Thus far an attempt to present a general overview of the state of development of basic space sciences in the Latin American region has been done. The remaining of this article highlights the most important projects and activities in individual countries.

Brazil

Of the Latin American countries the most advanced in space technology and basic research is Brazil. The country has an advanced infrastructure for space activities, with an ambitious agenda that includes the construction of four scientific satellites (SCD-1, SCD-2, SSP-1 and SSP-2), and the construction with China of a remote sensing satellite.

Research in space sciences is coordinated and funded through the civilian National Institute of Space Research (INPE) with headquarters in Sao Jose dos Campos in Sao Paulo. The INPE institute formally created in 1971 grew from the Commission of Space Activities (GOCNAE) established in 1961. The first projects conducted by INPE involved atmospheric studies with the launch of ionospheric probes. By mid 1970 the main projects conducted by INPE consisted of the MESA project for the reception and interpretation of images from meteorological satellites, the SERE project to use remote sensing technology from aircraft and satellites to be used in surveys of natural resources, and project SACI a geo-stationary communications satellite used to improve the education system. The end of the 70s decade was the beginning of the development of the first fully developed space technology project MECB (Complete Brazilian Space Mission).

The first results of the MECB program began appearing in the 90s. The first Brazilian satellite, SCD-1 is placed in orbit in 1993. In 1998 SCD-2 is successfully launched. In 1994 the CBERS-1 satellite developed in collaboration with China was launched from the Taiyuan base in China in 1999. Brazil also participates in the ISS.

A prototype detector of cosmic ray muons has been operating at the Southern Space Observatory, located at Sao Martinho da Serra, (29° S, 53° W). This project began in March 2001 under a scientific cooperation agreement between Brazil and Japan. The instruments observe cosmic ray precursors of geomagnetic storms and played a key role in the prototype network of muon observations together with two large detectors operating in Australia and Japan. The planned extension of the detector would complete the global coverage of Brazil's muon detector network. The prototype network has already detected the cosmic ray precursors of several magnetic storms as well as the precursory enhancements of cosmic ray anisotropy preceding the onset of geomagnetic storms.

Brazil has a 2.5% participation in the Gemini Observatory and more than 30% (together with the University of Virginia and the NOAO - National Optical Astronomical Observatory) in a 4-meter telescope currently in final stage of construction in Cerro Pachón (Chile) in the same place where the Gemini South telescope is located.

Argentina

The largest telescope in operation in Argentina is the 2.15-meter of the El Leoncito Astronomical Park in the Sanjuanina Mountains established in 1986. The University of Córdoba Observatory with a 1.52 meter reflector is the only observatory in LA that has functioned uninterrupted since its foundation in 1871. Argentina has a 2.5% participation in the Gemini Observatory (see report on Chile below).

Space science in Argentina is carried out by a civil organization and became firmly establish in 1992 with the SAC-B (Satelite de Aplicaciones Científicas) mission. The SAC-B was an international effort with the participation of Argentina, Brazil, US and Italy. Brazil contributed with its installations to control the satellite; Italy provided the solar panels of the spacecraft and one of its instruments. The scientific aim of the mission was to achieve observations of the bright, brief transient emissions of astronomical objects in the range 5 eV - 1 MeV. On board the SAC-B satellite there was an Argentine experiment of solar physics and a high energy astrophysics experiment of Penn State University. Unfortunately the SAC-B was lost during launch from NASA Wallop base in 1996 when the launcher could not release the experimental platform.

After the SAC-B accident the National Space Affairs Commission (CONAE) built the SAC-A satellite to demonstrate and test new technologies for future missions including newly developed solar panels. The NASA Shuttle placed SAC-A in orbit on December 12, 1998.

The Argentine SAC-C satellite was placed in orbit on November 21, 2000 by a Delta II 7320 rocket launched from the Vandenberg Base in California. The payload of SAC-C includes instruments developed by CONAE, NASA, the Italian Space Agency (ASI), CNES and the Danish Space Agency. The final tests were done in Brazil. The SAC-C together with LANDSAT 7, EO-1 and TERRA forms the "morning constellation" of satellites. The construction of these satellites and many other technological developments are conducted by INVAP a consortium of the National Atomic Energy Commission and the government of the province of Río Negro.

CONAE plans to build two new satellites: the SAOCOM as part of the SIASGE project of the Italian Space Agency for emergency management, and SAC-D with the participation of NASA. One of the scientific goals of SAC-D would be to measure the salinity of the ocean. CONAE's ground station is located 40 km from the city of Córdoba where several antennae are being operated, including one of 13 m diameter.

Argentina was chosen as the site to deploy the south component of the Auger Project, a large area ultra-high energy cosmic ray experiment operating in conjunction with a matching site in the northern hemisphere (Utah, in the US).

The construction of the austral observatory started in 2000. Prior to that, in 1995, an international collaboration had been formed including more than 200 scientists and technicians from 55 institutions in 16 countries. The Pierre Auger project studies the highest energy cosmic rays known in nature ($> 10^{19}$ eV) from a giant observatory spanning an area of 3,000 square kilometers located east of the Andes Mountains in the Province of Mendoza, Argentina. The expected arrival rate at these energies is only 1 particle per square kilometer per year (hence the large area requirements). The other distinctive feature, besides the exceptional size of the observatory, is the hybrid nature of the detectors. The experimental technique uses 24 fluorescence detector telescopes and 1,600 surface water tank detectors for Cerenkov radiation. The hybrid technology provides a large number of events with less systematic detection uncertainties and the best possible information about the primary particle types. The goal is to observe close to 1000 events during a 20 year period.

The first stage of construction and installation of the first detectors was completed in January 2002. Since then 30 detectors have been in operation and more than 70 air showers have been seen in hybrid mode confirming that the equipment operated within the design parameters.

Mexico

In Mexico the Autonomous National University (UNAM) has taken the lead in coordinating and promoting research and activities in space sciences. In January 1990 the UNAM established the University Program for Space Research and Development (PUIDE), comprising four areas: basic and applied research, aerospace engineering, teaching and space law. The UNAM together with the National Institute of Astrophysics, Optics, and Electronics (INAOE) participated in the 10-meter telescope project of the Instituto Astronómico de las Canarias (IAC). The Astronomical Institute of the UNAM has a 2.10-meter telescope installed in San Pedro Martir.

The INAOE, managed by the University of Sonora, in association with the University of Massachusetts at Amherst and with the financial and institutional help of the government of the state of Puebla is working on the construction of the Large Millimeter Telescope (LMT), an antenna 50 meter in diameter which is expected to start operations in 2004. LMT is the largest single dish being built. The telescope will be located on top of Sierra Negra at an altitude of 4,640 meters, 270 kilometers southeast of Mexico City. The US$ 86 million radio telescope will be used by astronomers to detect and study galaxies in all stages of evolution, measuring spectral lines from gases and radiation emitted from dust.

Chile

Because of its ideal geographic conditions (dry weather, high altitudes, south latitudes) Chile offers the best place for astronomical observations of the southern sky. This fact has attracted the attention of the international community of astronomers and has converted the country in the home of several of the best observatories in the world. A review of the large astronomical observatories in Chile follows.

Chile is participating in the Gemini project consisting of a pair of 8-meter telescopes in Hawaii (Mauna Kea at 4,200 meters altitude) and Chile. The project, managed by the US Associated Universities for Research in Astronomy (AURA), has a cost of US$ 184 million. The Gemini telescopes will provide unique, high- quality coverage of the entire sky in the infrared, optical, and ultraviolet spectral regions. The contribution to the project by country is US (50%), United Kingdom (25%), Canada (15%), Brazil (2.5%), Argentina (2.5%), Australia (5%). Chilean astronomers have automatic rights to 10% of the observation time in Gemini South and to any other international telescope in Chile.

The Cerro Tololo Inter-American Observatory opened in 1962 with support of the National Science Foundation. The site is located at 2,200 meters near the city of Vicuña. The most potent instrument of the observatory is a 4-meter telescope.

The European Southern Observatory (ESO) opened in 1969 on top of Cerro La Silla includes a 3.5-meter telescope. The infrastructure has expanded to Paranal in the north of Chile where 4 new 8-meter telescopes have been installed. These can be used independently or as an interferometer array (including the use of smaller telescopes).

The Carnegie Institution of Washington has an observatory in Cerro Las Campanas operating since 1976. The site is equipped with 3 telescopes including a 2.5 meter (the largest) and one owned by the University of Toronto. The Department of Terrestial Magnetism of the Carnegie Institution of Washington has cooperation with the Maip Radioastronomy Station located 30 kilometers southwest of Santiago.

The University of Chile inherited the instruments (including a Maksutov astrograph) left by Russian astronomers of the Pulkovo Observatory when they departed at the time the military regime took power in Chile.

The NSF and the ESO have signed an agreement to build the Atacama Large Millimeter Array (ALMA) in Chajnante in the Atacama desert in Chile at 5,000 meters altitude. The US$ 620 ALMA array will be used to study the formation of structures in the early universe. The ALMA interferometer consists of 64 movable 12-meter antennae with an extension of up to 14 kilometers. Completion of construction in the Chilean desert is scheduled for 2011.

The government of Japan through the Cultural Grant Aid has delivered in 1999 two 45-centimeter reflector telescopes to the National University of Asuncion, Paraguay and to the Observatory of Cerro Calán, Chile. Results of research on eclipsing variables has been already presented by researchers in Paraguay using one of the Japanese telescopes (11th UN/ESA Workshop on Basic Space Science will, Argentina 2002).

Other smaller groups of astronomers operating in Chile include the Astrophysics Group of the Chilean Catholic University in Santiago with a 91-cm reflector at Cerro San Cristóbal; the Isaac Newton Institute in Santiago,

Colombia

The National Astronomical Observatory (OAN) built in 1803 is the oldest observatory in the continent. The OAN is part of the National University in Bogotá and has a small team of researchers with strong emphasis in the areas of Cepheid variables, cluster membership, AGN, stellar physics and cosmology. The OAN offers a Masters degree in Astronomy and has a 3-meter refractor, a 2.25- meter telescope and several other smaller telescopes. In 1995 the OAN installed the GEM radio telescope in the town of Villa de Leyva (120 kilometers east of Bogotá). GEM radio maps of the galaxy at 408 MHz and 2.3 GHz were completed from data taken at the Villa de Leyva site during the first half of 1995 (Torres 2003)

Bolivia

Cosmic ray physics is a research field with deep roots in Latin America. It was through experiments conducted in the Chacaltaya Cosmic Ray Laboratory in Bolivia by the Brazilian physicist Cesar Lattes that the identities of the particles in pion decay were determined. The Chacaltaya

Laboratory, one of the oldest international laboratories in the region, is associated with the University of San Andres and was created in 1952. Scientists from Brazil, Japan, Argentina, England, India, Italy and the US have conducted leading edge cosmic ray experiments in Chacaltaya.

Concluding Remarks

There is no single magic recipe to follow in order to improve the conditions of researchers in space sciences in developing countries. The problem is a complex one and has long and historical roots that are not easy to change. One can however distinguish some key areas that need particular attention and can bring immediate change if applied vigorously. These can be summarized as follows: a) improving or creating computing and network infrastructure, b) supporting training programs and postgraduate studies for young researchers, c) creating incentives for good researchers so that they stay in their countries, thus helping to reduce brain drain, d) implementing educational programs for the public in space sciences in order to increase awareness and public support, and e) increasing international cooperation in research projects.

Of all the points mentioned above, improving the computer and network infrastructure is perhaps one whose impact can have the most immediate results. Nowadays there exist extensive data- archives on space sciences readily available at virtually no cost to any one with INTERNET access. Space missions of millions of dollars such as WMAP, COBE, ROSAT, IRAS, etc have made public releases of their data. The same data is available to a researcher in Germany or Nigeria provided that there is access to a computer network. Subsequent to the first results published by the COBE collaboration astronomers throughout the world started using the released data resulting in more than 160 papers produced. Certainly the re-analysis papers did not have associated with them the US$ 400 million price tag of the COBE project. For the first time it is possible to participate in "big science" on a budget. Computer networks also allow the access to electronic mail and electronic publications with no delay, solving the traditional problem of isolation and obsolete libraries in developing countries. An additional feature offered by computer networks is the possibility to have CPU power at a remote site, obviating the problem of having to buy expensive machines to install locally.

In summary, the task of the scientist is to bring to the public attention and to the attention of the politician the need to develop adequate conditions for research. To achieve this goal researchers needs to invoke the cooperation of the relevant local and international organizations. On the other hand, governments should never abandon support of the small research teams that show promise. The combined efforts of individual scientists and the actions of governments and international organizations could bring a change to the bleak situation faced by researchers in a world where market interests and social emergencies dictate where public spending goes. One must not forget that the joy of exploring the universe and the excitement of finding new discoveries belongs to the human culture as a whole, not just to a privileged group of countries.

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