Comisión Nacional de Investigación
Científica y Tecnológica - CONICYT

ASSOCIATIVE RESEARCH PROGRAM
BASAL FUNDING FOR SCIENTIFIC AND TECHNOLOGICAL CENTERS OF EXCELLENCE

FIRST PHASE TECHNICAL PROGRESS REPORT

GUIDELINES

The report should be written following the format specified hereafter. Once it is completed, it should be sent in printed and in electronic version to the address indicated below.
This is a technical report, a continuity plan and an economic /financial report will be asked later by the Program in due time.

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INDEX

I. PRESENTATION..3

II. EXECUTIVE SUMMARY..7

III. OBJECTIVES AND RESULTS OF THE DEVELOPMENT PLAN OF THE CENTER...............12

IV. ALLIANCES..32

V. PARTICIPATION OF COUNTERPART FUNDS..34

VI. APPLICATION OF THE RESEARCH RESULTS INTO ACTIONS THAT CONTRIBUTE TO INCREMENT THE COMPETITIVENESS OF CHILEAN ECONOMY (INDUSTRY, CIVIL SOCIETY AND PUBLIC BODIES OR POLICY MAKERS)..........................35

VII. OUTREACH AND DISSEMINATION..36

VIII. DEVELOPMENT AND AND IMPLEMENTATION OF INFRAESTRUCTURE........................38

IX. UNEXPECTED OR UNANTICIPATED OUTCOMES 40

X. PERFORMANCE INDICATORS..41

XI. FINANCIAL STATEMENT...44

XII. APPENDICES...45

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REPORT PERIOD : FIRST PHASE OF THE DEVELOPMENT PLAN

PERIOD COVERED : From April 1, 2008 to March 30, 2012
(INDICATE EXACT DATES)

I. PRESENTATION

NAME OF THE CENTER	**CODE**
Centro de Astrofísica y Tecnologías Afínes (CATA)	**PFB-06**

DIRECTOR OF THE CENTER	**Signature**
María Teresa Ruiz	
EXECUTIVE / DEPUTY / CO-DIRECTOR	**Signature**
Guido Garay	
MANAGER (if applicable)	**Signature**

SPONSORING INSTITUTION (if applicable)
Universidad de Chile
ASSOCIATED INSTITUTION (if applicable)
Pontificia Universidad Católica, Universidad de Concepción
CENTER WEBSITE ADDRESS[1]
www.cata.cl

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Research Lines of the Center
In case of changes over the period reported: 1) for research line replacements state the name of the original research line and the new one, 2) state also new research lines in case these were added over the period and 3) state old research lines that were closed over the reported period.

N°	Line Name	Objective	Principal Investigator	Other Investigator(s)
	Area 1	Birth and evolution of structures in the Universe	Leopoldo Infante	Barrientos, Bauer, Campusano, Cuadra, Demarco, Dunner, Escala, Galaz, Jordán, Lira, Lopez, Motta, Nagar, Padilla, Puzia, Quintana, Reisenegger, Treister
	Area 2	Stellar Populations in the Local Universe	Doug Geisler	Borissova, Catelan, Costa, Fellhauer, Gieren, Infante, Jordán, Minniti, Mendez, Muñoz, Pietrzynski, Richtler, Rubio, Zoccali
	Area 3	Distance Scale	Wolfgang Gieren	Costa, Hamuy, Mennickent, Minniti, Pietrzynski
	Area 4	Star Formation	Guido Garay	Barba, Bronfman, Casassus, Escala, Mardones, May, Rubio
	Area 5	Extrasolar planets and brown dwarfs	Dante Minniti	Geisler, Gieren, Jordan, Mendez, Pietrzynski, Rojo, Ruiz, Zocalli
	Area 6	Supernovae and Dark Matter	Mario Hamuy	Clocchiatti, Maza, Pignata, Reisenegger
	Area 7	Astronomical Instrumentation	Leonardo Bronfman	Altamirano, Bustos, May, Mena, Nagar, Vanzi
	Area 8	High Performance Astronomical Computing	Alejandro Clocchiatti	Cuadra, Escala, Padilla
	Area 9	Outreach	José Maza	Galaz, Nagar

Research personnel
Indicate any changes in the Staff of Principal Investigators and other Investigators over the period as compared to the original Development Plan mentioning reasons, relevance and results (if applicable).

There were no changes in the Staff of Principal Investigators.

Professor Jorge May, an Associate Investigator of CATA in charge of the day-to-day operation at the Millimeter Wave Laboratory, passed away on February of 2010. Being the father of the development of radio astronomical instrumentation in Chile, this constituted a tremendous loss for the Center.

Pablo Altamirano an engineer hired by CATA during 2009 on a full time basis as Manager of the ALMA Band 1 Prototype Receiver Project, left the Center during 2011 to take a job in ALMA. Due to his expertise on the design and construction of radio and mm receivers, thus was also an important loss for the Receiver Project.

Board of Directors and Advisory Committee

Indicate the updated names and participants of the Board of Directors and Advisory Committe. If either of these entities has not been formed over period or it is not currently in operation, please indicate why.

Describe and analize the role of these entities on the performance of the Center and in particular on the Development Plan. Indicate positive as well as possible neutral or negative outcomes.

The International Advisory Committee of CATA consists of three distinguished scientists with well-recognized international reputations and with experience in the direction and/or scientific operation of International Institutes or Observatories. Each year they review the annual report presented by the Director, make on site visits to the three institutions of the Center and deliver recommendations to be implemented by the Director regarding the scientific staff and the operation of the Center in general. It also recommended research priorities, in particular the build up of a group in theoretical astrophysics. The scientists that have served, at least for one year, as members of the International Advisory Committee are:

- Dr. Mark Phillips, Associate Director, Carnegie Observatories
- Dr. Michael West, Head of Science, European Southern Observatory
- Dr. Tom Wilson, Senior Scientist, ALMA-Project
- Dr. Lars Nyman, Head of Science Operations, ALMA
- Dr. Rainer Mauersberger, Commissioning Scientist, Joint ALMA Office.
- Dr. Jorge Ibsen, Head of Department of Computing, ALMA

We are extremely grateful to all members of the International Advisory Committee for their willingness to participate in the internal evaluation process of CATA and for the time invested in the preparation of written documents containing criticisms and suggestions which have been of great value for a most efficient running of the Center.

II. EXECUTIVE SUMMARY

This should be an executive summary of the progress made in the entire period.
In a maximum of **five** pages state a brief account of results and activities in research, student and young researchers' formation, dissemination, technological and knowledge transfer to non-academic domains.

The Atacama Desert in Chile is the best site for astronomical research on Earth. The astronomical facilities currently available in the north of Chile include some of the world's best optical and infrared telescopes, namely the Very Large Telescope, Gemini-South, and Magellan. In the Chajnantor area near San Pedro de Atacama there is a unique radio synthesis telescope: the Atacama Large Millimeter Array (ALMA). Operations started last year, and when finished (2013) it will consist of sixty six antennas, all working in concert to provide sub-arcsecond angular resolution. The privileged access of Chilean astronomers to this unparalleled suite of instruments provides them with a unique opportunity to address some of the most fundamental problems in modern astrophysics, such as how planets and stars assemble and evolve, how galaxies appear and grow, and what the structure of our universe actually is and what its ultimate fate will be.

The Centro de Astrofisica y Tecnologia Afines (CATA) is a unique venture among Chilean astronomers to generate the conditions for boosting astrophysics and placing Chile among the world leaders in this area. CATA is hosted by the Universidad de Chile at its Astronomy Department in Cerro Calán, and has as associated organizations the Astronomy Department of the Pontificia Universidad Católica and the Astronomy Department of the Universidad de Concepción. The main goals of the CATA are to produce a significant increase in the astronomical community working in Chile: researchers, students and specialized engineers, in order to meet, in the best possible way, the challenges posed by the newly available facilities and take advantage of the opportunity for technological developments associated with these foreign investments. The actions taken by the CATA during its first four years of operation have been very successful in pursuing these goals. CATA has also undertaken a vigorous effort in outreach. In what follows we summarize the main activities that have been carried out in research, human resources, formation and in the development of high technology.

1. Research

CATA is providing Chilean astronomers with the proper environment and tools to undertake the proposed research, giving them the opportunity to undertake ambitious Key projects which have put them at the forefront of astrophysics. These projects favour strong interaction among researchers and make the best use of all the available research facilities. There are six main areas of astrophysics cultivated by members of the Center:

- Birth and evolution of structures in the Universe
- Stellar populations in the local Universe
- The extragalactic distance scale
- Star formation
- Extrasolar planets and Brown dwarfs
- Supernova and dark energy

Each of the areas is led by a Principal Investigator (P.I.) who is responsible for the guiding progress in order to achieve the science goals expected in his or her area of research.

The scientific work performed in all six research areas of the CATA during the four years of operation has been considerable and fully in accord with the science goals as formulated in the original proposal. During this period, CATA members published 579 (five hundred and seventy nine) papers in refereed journals. CATA members have investigated various problems of fundamental scientific importance, covering the origins and nature of a broad range of objects, from the largest scales ---by studying galaxy formation and evolution---to the smallest scales---by studying the collapse of an individual star and the formation of planets. Given the ample scope of the research and the amount of work done by CATA members during these four years, a fair summary is impracticable. A more detailed report of the principal science results obtained during this period in each of the individual areas of research is presented in the Results section. The list of refereed (ISI) publications is presented in the Table. Three hundred and nineteen (319) contributions were published in non-refereed journals, most of them corresponding to proceedings of congresses (see Table). In summary, research activities in all areas proceeded intensely in-line with the initial science objectives and broadening their scope.

As highlights of the scientific work, in the following we list the Key Projects implemented by CATA in each of its research areas, shortly mentioning their scientific goals. These projects, in addition to fostering collaborations between researchers of the different astronomy sites within the country, carried out scientific programs that are beyond the scope of small research groups. All Key projects received considerable amounts of telescope time and have been extremely successful.

- Area 1: **MUSYC** (Multi-wavelength Survey by Yale-Chile). Deep infrared, optical and narrow band imaging of four 30´x30´ square fields, complemented with Chandra X-ray and Spitzer IR observations, with the goal of studying the formation and evolution of galaxies and of their central black holes.
- Area 2: **VVV Survey** (Vista Variables in the Via Lactea). IR variability survey with the goal of determining the 3-D structure of the bulge and inner disk using primary distance indicators, such as RR-Lyrae stars, and the age of the Milky Way stellar populations.
- Area 3: **The Araucaria Project.** Near Infrared photometry of variable stars with the goal of improving stellar standard candles, in particular Cepheid variables, to yield accurate distances to nearby galaxies (a few Mpc) and thus to be able to determinate the Hubble constant independent from Cosmic Microwave Background anisotropy studies.
- Area 4: **Massive stars forming regions in the southern hemisphere**. Galactic plane surveys at millimetre and submillimeter wavelengths, using state-of-the-art facilities, with the aim of finding, studying and understanding the earliest phases of the formation of massive stars.
- Area 5: **Extrasolar Planets**. Search, using the ESO VLT, for new extrasolar planets and measurements of their mass and radius. The main goal is to investigate the mass-radius diagram for low-mass objects including planets, brown dwarfs and late M-type stars.

2. Human resources

CATA has substantially contributed in the increase of the human resources devoted to astronomical research or astronomical instrumentation in each of its Associated Institutions. During these four years of operation a total of fourteen (14) new researchers were incorporated to the Center on a full-time basis: ten (10) astrophysicists and four (4) engineers. The new members were selected to fill expertise gaps in research areas, substantially broadening the research base in each astronomy site within the country, and have strengthened the teaching of astrophysics in all astronomy Ph.D. programs in the country. Particular efforts were made to incorporate engineers, theoreticians and sub-mm wavelength specialists in all the Associated Institutions. This proved to be crucial for achieving several of the scientific goals and to exploit the new generation of instruments located in Chile, in particular ALMA. Also during this period, CATA incorporated into the research and academic activities of the Center several scientists at the different institutions on a partial time-basis.

3. Formation

CATA has played a fundamental role in educating and training the new generations of young astronomers. These are the minds that will take full advantage of the unique opportunities available in Chile to carry out world-class research. The number of graduate students at the three Associated Institutions has steadily increased during the last four years, reaching a value of 82 students in 2011. One of the key ingredients in this accomplishment is support provided by CATA to graduate students, awarding full fellowships and stipends to participate in observing runs and attend congresses and workshops. In particular, the Key projects have broadened the range of thesis topics available to students today, allowing them to engage in first-class frontier research, thus having a big impact on the graduate programs. During the four years of operation twenty three (23) students obtained Ph.D. degrees and thirty four (34) students obtained Master degrees.

The newly hired scientists---specialists in astrophysical disciplines not cultivated by the founding members---have strengthened the teaching of astrophysics in all astronomy Ph.D. programs in the country, which are now fully conducted by Chilean universities. Center members offered graduate courses jointly to students of all Institutions, and supervision to students from any Institution. CATA made a vigorous effort to attract scientists with a background in theoretical astrophysics capable of providing the theoretical support needed for a high quality Ph.D. program in Astronomy. CATA has also actively supported the formation and consolidation of radio-astronomy groups at the associated universities, who will lead the development of mm- and sub-mm astronomy at their Institutions.

CATA has invited world experts on different astrophysical topics. The contribution of the visiting scientists has been remarkable, supplying the expertise needed for an expansion and broadening of the areas of research cultivated at the Center, and providing the theoretical support needed in the young Ph.D. programs. They usually give concentrated courses, during periods of 6 to 8 weeks. The joint venture in scientific research and academic duties carried out by the members of the different Institutions, together with the presence of visiting scientists, has generated new areas of research for graduates of all Institutions.

CATA also contributed to a substantial increase in the number of postdoctoral fellows at their associated Institutions, providing either full fellowships or resources for their travels and operations. Post-doctoral associates turn out to be key elements in establishing strong scientific collaborations between all associated astronomical Institutions.

4. National and International Collaborations

CATA is strongly promoting and fostering collaborations among astronomers working in related topics across the country, as well as internationally. In particular, CATA is encouraging scientists from the three Chilean institutions to work together in large collaborative projects that are beyond the scope of small research groups. Key programs have been already implemented and granted considerable amounts of observing time in several telescopes at the International Observatories in Chile. These programs enable Chilean astronomers to pursue more ambitious research goals than ever before, supporting the creation of large research groups and fostered close collaborations between members of different areas. Also CATA has enabled theorists and observers to join in common research projects. The large, as well as small more individual, projects are fulfilling one of the goals of CATA, which is to broaden the research base in each astronomy site within the country.

Thirty percent of the refereed papers published during the last four years have two or more CATA members as co-authors. Collaborative work among Center members is rapidly and steadily increasing with time, ensuring the fulfilment of one of the scientific goals of CATA which is to boost strong scientific collaborations between members of the different participant institutions. A quantitative measurement of this is provided by the *collaboration index* between Center members, measured from ISI publications, which grew from sixty five (65) in 2008 to two hundred and fourteen (214) in 2011, an increase in collaborations by more than a factor of three. About 20% of the papers involved postdoctoral fellows and 11% graduate students. A look at the list of authors of the papers by CATA members clearly shows that there is a well-established international collaboration in each of the ongoing science projects. In particular, the Key Projects involved a considerable number of international collaborators from all over the world, mainly from USA and Europe. There have been more than one hundred and seventy (170) visits between Center members and international collaborators (in both directions). The strong international partnerships have been one of the key to the scientific success of the Center.

Finally, in accordance with the strong commitment to increase human resources and networks for National Astronomy, CATA decided to foster collaborations and provide support for scientific activities to selected researchers at other Universities. These researchers are V. Motta and J. Borissova at the University of Valparaíso, R. Barba at University of La Serena and G. Pignata at University Andrés Bello (UAB).

5. Technological development

CATA is playing a key role in the development of high technology in Chile, supporting a number of initiatives of its members at the different Associated Institutions concerning technological innovation. The initiatives in astronomical instrumentation, high performance astronomical computing and robotics are developing at the expected pace and made significant progress towards reaching the main original objectives. All these projects are involving professors of electrical engineering and engineering students from the associated institutions. After four years of operations we see CATA as an important seed for the development of astronomical engineering in the country.

CATA has vigorously supported the development of instrumentation in astronomy in Chile, supporting the creation of a mm-wave laboratory at the Universidad de Chile ---aimed at developing receiver technology---, the creation of a High Performance Computing Center at Universidad Catolica ---aimed at providing to Center members the required computational capabilities to deal with the data acquired with the new mega-facilities as well as to perform numerical simulations---

and promoting the growth of radio-astronomical instrumentation facilities at Universidad de Concepción. All of these technology efforts are expected to have an important impact on the relation and access of Chilean engineers to the new astronomical Mega-projects being built in Chile, such as ALMA and the ELT.

The need for a mm-wave laboratory arises from the installation of the world's largest (sub)mm-wave telescope in Chile, the ALMA telescope, which presents a tremendous opportunity for the education and training of qualified personnel to support the development of engineering and of astronomical instrumentation in the country. The mm-wave laboratory at Cerro Calán Observatory is serving as a hands-on training for Chilean engineers and graduate students specializing in astronomical instrumentation. This laboratory is carrying out state-of-the-art projects in astronomical instrumentation, focusing on receiver development, in collaboration with recognized institutes (e.g. California Institute of Technology, ESO, University of Cologne, Harvard-Smithsonian Center for Astrophysics, Chalmers University of Technology). The goal is to boost the local development of the technological ability to design and construct receivers.

Almost all of the Key projects supported by the Center are surveys that are generating huge amounts of data. To deal with the vast flood of data from telescopes like VST, VISTA, and ALMA, the Center supported the creation of a National Data Center located at one of the Associated Institutions (PUC) which has committed additional resources and infrastructure. This National Data Center is serving not only astronomers at the Center for Astrophysics but also the rest of the Chilean astronomical community, providing quick and easy access to the data and thus promoting better research.

6. Outreach

CATA is convinced that a strong link with society is invaluable, and thus is carrying out a vigorous policy of outreach and general education, supporting and funding important activities directed to the general public, high-school students and their teachers. To enhance the interest and culture in astronomy in the community several actions have taken at the three associated Institutions. A Visitor Center was built at the Universidad de Concepción, while at Universidad de Chile the Center funded the purchase of three portable telescopes for *Project Carina,* a Center project designed to educate high school students of public schools in the neighborhoods of Santiago. Most Center members were involved in outreach activities at different levels. Press Releases and media diffusion of scientific results from Center members were frequently made.

Among the highlights in Outreach we mention the publication of a series of astronomy book directed at the general public but with emphasis on high-school students, written and edited in full by CATA members. The first four volumes are: "Hijos de las estrellas" by María Teresa Ruiz; "Mundos lejanos", by Dante Minniti; "Con ojos de gigantes" by Felipe Barrientos and Sebastián López; and "Supernovas" by Mario Hamuy and José Maza. Other books of outreach supported by CATA are "Estrellas Variables" by Ronald Mennickent and "El Universo: Ciencia y ficción" written by Maria Teresa Ruiz, an innovative book designed for children between 8 and 14 years.

Finally, CATA is supporting the training of high school science teachers. So far, more than one hundred science teachers coming from all over the country have been trained in astronomy for a week at Cerro Calán Observatory where they received lectures, practical sessions, observing sessions and a large quantity of material including a special booklet prepared and printed for them.

III. OBJECTIVES AND RESULTS OF THE DEVELOPMENT PLAN OF THE CENTER

Considering the objectives established for the first five-year period in the Development Plan describe, in no more than **20** pages, the most relevant results achieved during the period reported. Include here aspects of research, human capital formation, activities to support other national groups, international exchange, dissemination to non-academic, and knowledge transfer. Explain the changes in objectives, if applicable, over the period expected due to the dynamics of these Centers.

RESULTS

1. RESEARCH

The six areas of research of CATA have been very active and productive, given rise to 579 (five hundred seventy nine) ISI publications during the reported period. Thus, it is unrealistic to try to summarize in this report all the work and the results obtained in these 4 years of research. Instead in what follows we highlight the most important results in each of the individual areas of research. In particular we emphasize the Key Projects of each area which have become internationally recognized as high-impact large-scale scientific projects associated to CATA.

AREA 1: Birth and Evolution of Structures in the Universe.
P.I.: Leopoldo Infante

The long-term goal of Area 1 is to contribute in the understanding of the nature and evolution of structures in the universe. Faculty members doing research in this Area include Barrientos, Bauer, Bronfman, Cuadra, Galaz, Dunner, Jordán, Lira, López, Minniti, Padilla, Quintana, Reisenegger and Richtler.

This Area emphasizes the study of primeval galaxies, clusters of galaxies and dwarf galaxies, and is carrying out with prominence large surveys of high redshift galaxies, superclusters and clusters of galaxies. It developed from no theory at all to a significant amount of cosmological simulations, galaxy evolution simulations and primordial star formation theory at redshifts greater than 11.

One important objective envisioned in the original project was to prepare the extragalactic community for the ALMA era. At that time there were no extragalactic radio astronomers in our community. Today, after these fours years, we are pleased to say that this objective is being accomplished. Proof of this is the increase in the number of faculty, postdoctoral fellows and students working in projects related to ALMA and the number of extragalactic proposal submitted in cycle 0 to ALMA; 11 out of 34 proposals. These proposals range in topics from studies of the local universe to quasars, AGN, star forming galaxies at z~1-3 to submm emission in the most distant galaxies ever discovered at z>7.

In what follows we highlight three lines of research that are been carried out successfully in Area 1: the MUSYC survey, the QbC project and Cosmo-galaxy simulations. We also mention the latest result, the discovery of the largest and most powerful distant cluster of galaxies ever discovered (El Gordo), which recently received worldwide media attention.

Simulations and theory: Simulations of structure and galaxy formation is one of the major new advances in Area 1, allowing Center members to become competitive in the field. Highlights of this specific area include: a first, physically based, definition of a galaxy supercluster; simulations which show that dark matter merges and that gas accretion into dark matter haloes generate turbulent and supersonic environments, where cooling molecules trigger primordial star formation; simulations of the universe at several different scales, from the large-scale structure, to the physics of galaxy formation, to the dynamics of star forming regions, to the inner pc scales of central supermassive black-holes, both via semi-analytic models and full hydrodynamic simulations.

Quasars behind Clusters (QbC) survey: This survey is aimed at studying the effect of galaxy group and cluster-sized environments on the gaseous content of galaxies at redshifts $0.2<z<0.9$. To this end, the QbC probes MgII absorbing galaxies along sight lines to background QSOs that were selected to be in close projection to foreground cluster galaxies. MgII, a known tracer of cold (logT~4) gas in the circumgalactic medium, was found more frequently in the line-of-sight toward clusters of galaxies. This effect was particularly important for strong MgII absorbers.

MUSYC (MUltiwavelength Survey by Yale-Chile)**:** The main design of this survey is to study formation and evolution of galaxies and their black holes at redshifts z~3. It includes deep infrared, optical and narrow band imaging and covers four 30x30 square arc-minute fields. Also, Chandra X-ray observations, Spitzer IR imaging and extensive spectroscopy were carried out. The survey has been most successful for studies of Lyman Alpha Emitting galaxies (LAE) at redshift z~3. Center members were able to determine spectral energy distributions of these galaxies, showing that on average these galaxies are quite blue and dust free. On the other hand, given the large volume surveyed, they were able to obtain a large sample of LAEs at z~3.1, which allowed us to make robust estimates of three important physical quantities: the luminosity function, the number density and the clustering length. The latter allowed them to estimate masses and number densities of the dark matter haloes where LAEs reside. They were able to reach the conclusion that these haloes may host galaxies like the Milk Way at present. Furthermore, the use of narrow band data enabled them to extend the survey to lower redshifts of z~2, such that they could constrain the clustering properties and measured the evolution of the luminosity function of LAEs between redshifts 3.1 and 2.1.

EL GORDO: Since 2008 CATA members have been reporting results from their Atacama Cosmology Telescope (ACT) survey collaboration which includes USA and Chile astronomers and physicists. The ACT is a submm radio telescope built to measure the Cosmic Microwave Background radiation (CMB) at high resolution. It is located in Cerro El Toco near the ALMA site in Chile. The Center group has been in charge of detecting clusters of galaxies through the Sunyae-Zeldovic (SZ) imprint in the CMB. Once a cluster is detected they carry out follow up spectroscopic (VLT and Gemini) and imaging (SOAR) observations. A number of clusters have been discovered, normally very massive, at redshifts ranging from 0.3 to 1. One of these clusters, now called "EL Gordo", is the most massive and powerful distant cluster ever detected. Using X-ray Chandra observations, NIR SOAR imaging and VLT spectroscopy, they estimated its intrinsic mass and luminosity. Its redshift, z=0.87, puts this cluster at an age close to half the age of the universe, 7 billion years. The fact that such a large mass concentration (gravitationally bound and in equilibrium) existed in the early universe puts stringent constraints on current models of dark matter and dark energy cosmology.

AREA 2. Stellar Populations in the Local Universe
P.I.: Doug Geisler

The science cultivated in this Area involves researchers from all 3 institutions, including 14 faculty members (Borissova, Catelan, Costa, Geisler, Gieren, Infante, Jordan, Mendez, Mennickent, Minniti, Pietrzynski, Richtler, Rubio and Zoccali), several postdoctoral fellows and graduate students. The overarching scientific goals of Area 2 are closely aligned with those of Area 1, viz. to study the formation and evolution of structures, in particular galaxies, but using the resolved stars within a galaxy instead of its global, integrated properties as tracers. Obviously, a great deal more information can be gleaned for nearby systems whose individual stars are available to tell us about the details of the secrets of their formation and evolution. The observational techniques are also different. In particular, the main goals are to investigate galaxy (and the Galaxy) formation and evolution, in particular dynamical and chemical evolution. Much of this work is often relegated to the realm of cosmology, the study of the very distant Universe and its nature on very large scales and at very large distances, where only very crude details can be drawn from the limited data. One of the great advantages of this Area is that one can perform 'near-field' cosmology and obtain much more detailed and accurate data for nearby galaxies which perfectly complement what can be learned from the distant Universe. Work was divided into 3 main subtopics: globular cluster systems of more distant galaxies, stellar populations in nearby galaxies, and stellar populations in the Galaxy.

Globular Cluster Systems. *The Dark Matter Halo of NGC 1399*. Central galaxies in galaxy clusters can be key discriminators between competing theories of galaxy formation and dynamics; in particular between the cold dark matter (CDM) paradigm and modified Newtonian dynamics (MOND). However, one requires a very large number of dynamical probes over a wide radial range in the galaxy to definitively discriminate between model predictions. CATA members used globular clusters as tracers of the gravitational potential of NGC 1399, the central galaxy of the nearby Fornax cluster. Using several instruments they obtained velocities of 656 globular clusters out to a galactocentric distance of 80 kpc. This represents the largest sample of dynamical probes so far obtained for any galaxy. They then performed a careful Jeans analysis for a non-rotating isotropic model and compared their results to different dynamical predictions. A generic NFW CDM model fits their data well, while a MOND model requires additional dark matter on the order of the stellar mass in order to get good agreement. This work involved extensive interaction with Area 1 researchers.

Stellar Populations in Nearby Galaxies. *Chemical Evolution of the Galactic Bulge*. Does the Milky Way possess a "classic" bulge, formed very rapidly and very early in the history of our Galaxy, or is it instead a "pseudo-bulge" formed via secular evolution of the disk driven by a bar over an extended time? The answer has important implications for Galaxy formation theories and can be constrained from detailed chemical studies - elemental ratios are sensitive to the previous history of star formation. In particular, the relative abundances of iron and alpha-elements play a key role: the [alpha/Fe] ratio depends on the relative contribution of SNII and SNIa progenitors, and therefore it depends on the timescale of star-formation, as these two processes have very different timescales. Center members obtained high resolution spectra for a large sample of bulge giants and measured alpha and Fe abundances. [alpha/Fe] is found to be higher in bulge stars than in thick disk stars, which were known to be more alpha enhanced than thin disk stars. These results support a scenario in which the bulge formed before and more rapidly than either thin or thick disks, and therefore our bulge is a prototypical old spheroid, with a formation history similar to that of early-type (elliptical) galaxies.

The VVV Survey. The Vista Variables in the Via Lactea Survey (D. Minniti PI) is the public ESO near-IR variability survey scanning the Milky Way bulge and an adjacent section of the disk. The survey will take 1929 hours of observations with the ESO 4-m VISTA telescope during 5 years (2010 - 2014), covering 10^9 point sources across an area of 520deg^2. The final product will be a deep near-IR atlas in five passbands (0.9-2.5 μm) and a catalogue of more than 10^6 variable point sources. The VVV is the Key Project of Area 2 and is proving to be every bit as much of a goldmine as anticipated. Despite only recently beginning, the Survey has already produced a number of important scientific results and papers. One of the key scientific goals of the VVV is to study star clusters in the Galaxy, including 33 known globular clusters and ~350 known open clusters. Most of these suffer from large and often variable reddening and are thus very poorly studied. The VVV survey will add very substantially to the knowledge of their basic parameters. The VVV is also discovering and studying a wealth of new star clusters. Center members reported (see ESO Press Release 1128) the discovery of ~100 new open star clusters. These are so-called embedded clusters - very young and still surrounded by their cocoons of dust and gas, and thus invisible to optical surveys. But they could not escape the sensitive IR images of the VVV, which penetrate the obscuring interstellar material to reveal the clusters. It has also long been suspected that there are several more globular clusters - much older than open clusters - that are hiding in the obscured and dense regions of the Galactic bulge, and indeed VVV has now found at least 2 new old globular clusters. In addition, very strong synergy has been established with the distance scale work of Area 3. A huge number of RR Lyrae stars, classical population II distance indicators, will be observed in the VVV, allowing extremely accurate distances to be determined to many globular clusters, as well as the bulge and the Sagittarius dwarf galaxy, also allowing us to measure the size of these latter objects.

Multiple Populations in Globular Clusters. Globular clusters, long considered as the prototype of simple stellar populations, have recently been found instead to be more complex, and thus more interesting, than regarded by this traditional wisdom. In particular it has been discovered that the most massive globular clusters have chemical inhomogeneities. In addition, it has been found that a growing number of clusters have an intrinsic spread in the content of their light-elements. The generic phenomenon is labeled multiple populations. These results point toward the fact that globular clusters are not the simple systems previously thought, but had a period of chemical evolution and distinct episodes of star formation at the beginning of their life. This has led to a paradigm shift in our understanding of these key astrophysical objects. The observed spread is probably due to the early evolution of each cluster, when a second generation of stars was born from gas polluted by ejecta of evolved stars of the first generation. Several kinds of polluters have been proposed, including intermediate mass AGB stars and massive main sequence stars. Center members have been involved in a number of investigations to try and shed light on this fascinating phenomenon. They studied stars in NGC1851 belonging to the two RGBs visible in the Stromgren CMD, finding that the double RGB appears to be related to a bimodal distribution of the light and heavy s-element abundances. The cluster also hosts a bimodal SGB, which was theoretically explained with two populations having the same age but different C+N+O content. They proved instead that stars in NGC 1851 share the same C+N+O content. In this case pollution by SNeII appears to have ocurred. On the other hand, for M4 Center members established that the cluster is formed by two stellar populations with distinct patterns of light and light-s elements. These patterns suggest that the second generation was formed by material polluted by ejecta of massive stars ($M > 15M_{\odot}$). This implies an age difference between the two populations of 10-40 Myrs.

AREA 3. The Extragalactic Distance Scale
P.I.: Wolfgang Gieren

The work in Area 3 has been mainly conducted by four Center scientists (Gieren, Pietrzynski, Mennickent and Minniti), several postdoctoral fellows and students, and a considerable number of international collaborators from the USA and Europe. The main science and Key Project of this Area is the **Araucaria Project** whose goal was to improve stellar standard candles, and in particular Cepheid variables, to yield distances to nearby galaxies (out to a few Mpc) accurate at the few percent level and this way lay the ground for a truly accurate (<3%) determination of the Hubble constant independent from CMB anisotropy studies. The Araucaria Project is very complementary to the HST Key Project on the Extragalactic Distance Scale by Freedman et al. (2001) and addresses the 3 largest sources of systematic uncertainty in that project which had limited the accuracy of the Hubble constant from the Cepheid approach to 10 percent: reddening of the Cepheids; the little-known metallicity dependence of the Cepheid period-luminosity (PL) relation; and the distance to the fiducial galaxy, the Large Magellanic Cloud (LMC). The strategy adopted to reduce the errors from these sources were a) measure Cepheid distances from near-infrared photometry, reducing the importance of reddening errors quite dramatically; b) select a sample of nearby late-type galaxies exhibiting a broad variety in the (mean) metallicity of their young stellar populations, and looking for systematic effects related to the metallicity; and use a number of different stellar methods to measure the LMC distance and compare the results (this ended up in getting the most accurate results from late-type eclipsing binaries composed of two red giants which we found in the LMC (and SMC) from OGLE 2 and OGLE 3 data; see later in this report). Besides of Cepheids, the Araucaria Project has contributed on the improvement of other stellar techniques of distances measurement, and applied them to nearby galaxies: RR Lyrae stars, red clump giants, TRGB, blue supergiants and eclipsing binaries, with the first 3 methods all calibrated in the near-infrared to minimize effects of reddening and metallicity.

In the Cepheid work, CATA members performed as a first step wide-field optical searches for Cepheids in the Araucaria target galaxies, which included all Local Group irregulars and 4 spiral galaxies in the Sculptor Group (NGC 55, 247, 300 and 7793). The ground-breaking initial work was conducted in NGC 300 where they found 117 classical Cepheid variables with periods between 5-115 days. In a follow-up study they obtained near-IR photometry at the ESO VLT for a subsample of these Cepheids and developed a multi-wavelength VIJK technique to determine the distance to NGC 300 with a total error of 3%, unprecedentedly small. This technique was later applied to all other Araucaria target galaxies and yielded in all cases Cepheid distances accurate to better than 5%. Since the project involved a huge observational effort, members applied for and were granted numerous semestral programs at the ESO Paranal and La Silla observatories, and at Las Campanas Observatory (Magellan, Warsaw 1.3-m imaging telescope used for the OGLE Project). Most of the wide-field imaging surveys for Cepheids and the other stellar candles were conducted with the Warsaw telescope in which members were allocated observing time in many nights, to allow proper phase coverage of the variables and making the Cepheid work possible.

Comparing the observed Cepheid PL relations in all target galaxies of the Araucaria Project led to the conclusion that the slope of the PL relation is universal, that is metallicity-independent, in the broad range from -0.3 dex (LMC) to -1.0 dex (WLM). This result was extended to solar metallicity (which is important because most HST KP galaxies have ~solar metallicity in their central regions) by another project undertaken by our group: the application of the Baade-Wesselink-type **Infrared**

Comisión Nacional de Investigación Científica y Tecnológica - CONICYT

Surface Brightness (IRSB) Technique for Cepheids to Milky Way and Magellanic Cloud Cepheids. This technique establishes Cepheid angular diameters from their measured (V-K) colors using a surface brightness-color calibration obtained from VLTI interferometry of nearby Cepheids, and combines these with their radius variations obtained from integrating their observed radial velocity curves. The largest source of systematic error in the method comes from the p-factor needed to transform the observed radial velocities of a Cepheid into the pulsational velocity at its surface. To determine the "p-factor law" this Center group did theoretical work using theoretical Cepheid atmospheres, and provided an improved empirical calibration by applying the IRSB technique for the first time to Cepheids in the LMC; using the constraint that individual LMC Cepheid distances cannot depend on their pulsation period (they are all very nearly at the same distance!), together with the HST FGS parallaxes measured by Benedict et al (2007) for ten nearby Milky Way Cepheids which basically set the zero point of the method, they found that the Cepheid PL relations in Milky Way and LMC do show exactly the same slopes, particularly in the near-IR J and K bands, and that there is also no significant metallicity effect on the zero points.

As a conclusion, the work on the Cepheid PL relation from both the Araucaria Project approach, and the IRSB technique has yielded, as a very firm result, that the **Cepheid PL relations in the near-infrared J and K bands are truly universal**, unaffected by the metallities of the observed Cepheid samples. The IRSB distances to 36 LMC Cepheids have further yieldes an accurate LMC barycenter distance of 18.45 mag, with a 5% systematic error and in line with our first analyzed late-type eclipsing binary system (see next section).

Center members discovered from OGLE 2 data the first 8 eclipsing binaries in the LMC composed of two **red giants**, bright enough for measuring accurate orbital radial velocity curves with 4-8-m class telescopes. These systems have an enormous potential for accurate distance determinations, and for precision measurements of the masses and radii of their component stars. Observationally, they are difficult targets because of their very long orbital periods, typically 100-500 days. The first analyzed system yielded indeed a distance accurate to 2.7%. From OGLE 3 images they detected 16 additional systems which are all being observed with high-resolution spectroscopy. Once the 10-15 best LMC systems have been fully analyzed by the Center group, with individual distances accurate in the 2-3% range, they expect to determine the LMC barycenter distance to 2%. This will mean a breakthrough in comparison to the HST Key Project´s assumed LMC distance of 18.50 which was uncertain to 10% at the time.

As part of the LMC eclipsing binary programme, members were lucky enough to detect the first ever two classical Cepheids in eclipsing systems with a stable red giant star as a companion in both cases. This allowed them to solve the famous "Cepheid mass discrepancy problem" in favour of the pulsation mass, given that the Cepheid dynamical masses could be measured to 1%. The result was published in Nature (also see ESO Press Release 1046, 2010). Due to this result and the disappearance of the annoying mass problem, Cepheids are now an even more reliable tool for calibrating the first rungs of the distance ladder.

Through the collaboration in the Araucaria Project with the University of Hawaii group, Center members achieved to set up a completely new, and first **spectroscopic** stellar method to measure precision distances out to at least 10 Mpc with blue supergiant stars. The accuracy is very competitive (5% with 10 blue supergiants in a given galaxy), has the advantage of yielding individual metallicities and reddenings as a byproduct, and uses the brightest normal stars in the Universe.

AREA 4. Star Formation
P.I.: Guido Garay.

The main scientific goal of this area is to understand and characterize the formation process of low and high mass stars that takes place within dense molecular cores. Faculty members doing research in this Area include Bronfman, Casassus, Escala, Garay, Mardones, May and Rubio, several postdoctoral fellows and more than 15 thesis students.

The Key Project in this Area, entitled *Studies of massive star forming regions in the southern hemisphere*, has been designed to specifically undertake a thorough study of the formation process of high-mass stars within massive dense cores, in particular to determine the gas kinematics prior to and during the onset of the gravitational contraction. The first part of this Key Project, already completed, consisted of a survey of 1.2 mm dust continuum emission towards a large sample of luminous massive star forming regions, made using SEST/SIMBA. This survey allowed Center members to determine the physical characteristics of the molecular cores harboring high-mass YSOs. They showed that the formation of massive stars takes place in molecular structures with distinct physical parameters, namely sizes of ~0.4 pc, dust temperatures of ~30 K, masses of ~2000 Msun, column densities of ~$3x10^{23}$ cm^{-2}, and densities of ~$4x10^5$ cm^{-3}. The observed radial intensity profiles of these massive and dense cores are well fitted with power-law intensity profiles, indicating that they are centrally condensed. They also found that the ultra-compact H II regions detected towards these objects are usually projected at their peak position, suggesting that massive stars are formed at the center of the centrally condensed massive and dense cores.

As a byproduct of the 1.2 mm dust continuum emission survey, Center members discovered the first few luminous objects without counterparts at mid-infrared (Midcourse Space Experiment [MSX]) and far-infrared (IRAS) wavelengths. These clouds have sizes of 0.2-0.3 pc, masses of typically 1000 Msun, densities of ~2×10^5 cm^{-3}, and dust temperatures < 17 K. They concluded that these objects correspond to massive, dense and cold cores in very early stages of evolution, prior to the formation of a central massive object and that will eventually collapse to form high-mass stars.

Soon after the ASTE and APEX telescopes became operationally, CATA members started the second part of the Key project. This consisted in a galactic survey of the dust continuum emission at 850 microns. Center members joined forces with the European ATLASGAL team to carry out a survey of the whole Galactic plane using LABOCA, allowing them locate in an unbiased way the cold and dense massive molecular cores wherein massive starts will eventually form.

Follow up work is being done using a variety of instruments available in order to: (a) investigate the dynamic interaction between embedded massive protostars and their parent cores; (b) Study the spatial distribution of massive protostars within GMCs and across the inner galaxy; and (c) Investigate the origin of jets and molecular outflows. One of the major astronomical results of the last two decades has been the discovery that star formation is accompanied by energetic, collimated mass outflow. The driving mechanism is however unknown and requires study on scales as close to the star as possible. Center members made an unbiased search of ionized jets, using ATCA, towards high-mass YSOs candidates. They found that the phenomena of highly collimated stellar wind is also present in the most luminous massive protostars yet known, and concluded that the lifetime of this phase in high-mass YSOs last for only $3x10^4$ yrs. They also studied the characteristics of high velocity molecular gas towards massive young stellar objects and investigated whether or not the ionized jets have enough momentum to drive the bipolar molecular outflows.

Center members are also carrying out studies of Infrared Dark Clouds, namely cold, dense molecular clouds seen as extinction features against the bright Galactic infrared background. They have mapped the emission in several molecular lines, using MOPRA, toward a large number of filamentary IRDCs in order to better characterize the various stages of high-mass star formation as well as the timescales and physical conditions during the collapse into proto-stellar cores. In addition, Center members are part of a large international project (MALT90) to make maps in 16 molecular lines near 90 GHz, using MOPRA, of 3,000 dense cores in the galactic plane. These molecular lines will probe the physical conditions, chemical state, and evolutionary state of 3,000 dense molecular cores in a wide range of evolutionary states (from pre-stellar cores, to proto-stellar cores, and on to H II regions).

Finally, Center members are building up data on the topic of the gas content in proto-planetary disks, and also on signs for on-going planet accretion. Molecular lines were observed with APEX towards a dozen of high mass star forming cores showing kinematical signatures for the presence of a rotating disk. The aim is to search for enhanced abundance of certain molecular species based on the prediction from chemical models of disks. This will provide reliable candidates to spatially resolve a disk surrounding a high mass star with the ALMA telescope.

In summary, CATA members have been able to study and characterize the long-sought onset of massive star formation within cores. The Key project of this Area turned out to be a strong pathfinder for ALMA studies. Center members are now ready to begin use ALMA to study the density structure and kinematics of massive protostellar envelopes, inner disks and winds at sub-arcsecond resolution, yielding detailed information on massive star forming cores at scales of 10 – 100 AU.

AREA 5. Extrasolar Planets and Brown Dwarfs
P. I.: D. Minniti

More than ten researchers were involved in the successful development of this new area of research. Faculty members include: Borissova, Geisler, Gieren, Jordan, Kurtev, Mendez, Minniti, Pietrzynski, Rojo, Ruiz and Zoccali.

Undoubtedly the biggest success in research of Area 5 has been the creation of large key programmes, which reach far beyond the normal scientific activities. These large key programmes developed slowly at the beginning, but already started to bring fruits after only a few years of operation, and the future looks most promising. The large programmes in line with the scientific goals of Area 5 are:

(1) ESO Large Programme 666 on Extrasolar Planets at the ESO VLT. This, the Key Project of the Area, has produced a considerable number of newly discovered objects for which the main physical parameters were determined. These data are allowing to test the different planetary models of atmospheres, of internal structure, and of evolution, of objects at the bottom of the main sequence and beyond.

(2) The HAT-South Planet Search Programme at Las Campanas Observatory. This is a global network of small, custom made telescopes that were installed during 2009 in Australia (Siding

Springs), Namibia (HESS site) and Chile (Las Campanas), and that is providing 24-hr monitoring of selected fields to discover transiting exoplanets more efficiently than ever before. Euler/CORALIE and duPont/Echelle runs to confirm transiting exoplanet candidates from HATnet.

(3) The Magellan Planet Search Programme at Las Campanas Observatory. This radial velocity search for planets made a dozen new discoveries. Center members are now finishing up a study of the HK chromospheric activity of a large sample of stars and improving the precision of M-dwarf radial velocity observations, which resulted in the discovery of the super-Earth in the habitable zone of GJ667c;

(4) The Calan-Hertfordshire Extrasolar Planet Search (CHEPS) survey with HARPS and CORALIE. Even though the project is still very much in its infancy, discoveries and orbits have been published for three exoplanets and a brown dwarf, or extreme Jupiter-like planet. The target selection was done using FEROS, with two publications of chromospheric activities, kinematics, rotational velocities, and metallicities for a sample of over 950 nearby, Sun-like stars.

Another initiative involves perfecting new techniques to measure exoplanetary atmospheres and proto-planetary disks. A first attempt involves using high-resolution IR spectrographs, available to the Chilean community, to attempt detecting the Doppler wobble of the exo-atmospheric molecular lines. These studies will be complemented later with ALMA, to ultimately gain new knowledge of planetary "weather", the structure of atmospheric wind and the variations in chemical constituents. Studies of proto-planetary disks will also be carried out using the recently available IR facilities. Future ALMA observations will provide definite answers regarding their formation and evolution.

Among other on going research projects we mention:

- Planet search around bright giant stars in the southern hemisphere using the FEROS and FECH spectrographs;
- Search for proto-BDs in Barnard 30. A few candidates have been already detected with APEX;
- Search for cool Brown Dwarfs (UCDs) using VVV. Center members developed a set of automatic procedures for identification, reduced proper motion and photometric classification of the UCD population using VVV catalogs. As a result a candidate list from late-M to T-Y spectral types was built. A massive campaign for spectral follow up on VLT, Magellan, SOAR and du Pont telescopes is in course;
- Spectral synthesis analysis of main sequence and subgiant stars using FEROS optical spectroscopy. Center members are applying a new method for abundance analysis of Sun-like stars to a large sample of stars to analyse them for future planet search and also for analysis of abundance trends in the galaxy;
- Search for wide brown dwarf binaries to white dwarfs and subgiant stars. As part of this effort, Center members discovered the first white dwarf - T-dwarf binary system.

AREA 6. Supernovae and Dark Energy.
P. I.: M. Hamuy

The long-term goals of Area 6 are twofold: (1) The determination of extragalactic distances using supernovae, and (2) the understanding of the physics of supernovae and of dark energy. Faculty members doing research in this Area include: Clocchiatti, Hamuy, Gieren, Maza, and Pignata. The activities performed during the reported period along these two lines are summarized below.

Since the beginning of our activities on 2008, CATA members have carried out a complete study of nearby supernovae (SN) in order to understand the origin of the dark energy of the Universe and its properties. With this in mind, the SN group carried out (1) a nearby supernovae search ($z<0.03$) in the southern hemisphere with four of the six robotic PROMPT telescopes in Cerro Tololo, which are available for them to use, and (2) a follow-up program, in close collaboration with the *Carnegie Supernova Project*, to establish a database with hundreds of nearby supernovae ($z<0.07$) of both thermonuclear and gravitational core collapse nature in optical and infrared (IR) wavelengths.

The first step along this research line consists in discovering supernovae. With this purpose Center members are carrying out a systematic search of several hundred galaxies using four of the six PROMPT robotic telescopes at Cerro Tololo. This project, which involves the participation of several undergraduate students, has secured more than 1120 hours of observation each year. Every night, several hundred galaxies are observed, the images are downloaded to our computers in Santiago, and an automatic search pipeline is triggered. During 2008-2012 the search project, dubbed CHASE, discovered 150 nearby supernovae. The supernovae discovered by CHASE are all nearby and generally young supernovae ($cz < 25000$ km s^{-1}).

The second step in this research line is obtaining photometric and spectrometric follow-up data for the discovered supernovae by CHASE (and additional equatorial or southern supernovae found at other observatories). This project was done in collaboration with the Carnegie Supernova Program that used 280 nights every year, between 2004-2009, in the 1 and 2.5m telescopes in the Las Campanas Observatory, in the north of Chile, to study supernovae with redshifts less than 0.07. The collaboration with CSP observed a total of 129 Type Ia supernovae, in the ugriYJHK filters and with optical spectrographs. So far, Center members have analyzed the first batch of 35 supernovae. Based on the light curves, they were able to derive parameters which are used in distance determinations, such as the time and magnitude at maximum light, and the decline rate, $\Delta m15(B)$. Furthermore, they built a set of template light curves which are of general use for fitting Type Ia supernova data from any source. Using the light-curve parameters, we calibrated intrinsic colors at maximum light and thus derived color excesses. The availability of optical-NIR colors allowed them to study the properties of the reddening law in the host galaxies, which is a fundamental step in controlling possible systematic errors involved in the measurement of distances with Type Ia supernovae. They found that the group of supernovae which suffered small or moderate reddening favored a low value of the total-to-selective absorption coefficient of $Rv=3.2$ which is typical for the Galaxy, whereas the two supernovae in the sample with highest reddening yielded significantly lower values ($Rv\sim1.5$). They studied in detail the cases of these two supernovae by comparing with alternative models of reddening by dust in a dense circumstellar shell. One of the main goals of the work was to calibrate Type Ia supernovae as distance indicators. For this purpose they fit the absolute magnitudes at maximum light in each of the ten photometric bands as a function of $\Delta m15(B)$ and of the color at

maximum or, alternatively, the color excess. The results for all bands showed dispersions of ~0.10-0.15 mag in the calibration of the absolute magnitudes (i.e., a precision of ~6% in the distance.) We noticed a strong correlation among the residuals of the fits in all bands, especially in the optical. These correlations allowed them, by combining results from different bands, to estimate that the precision in the measurement of the absolute magnitude of a Type Ia supernova can be as low as ~0.06 mag (~3% in distance.) Regarding the reddening law, the fits yielded low values of Rv~1-2 in all cases, contrary to what was found through the analysis of color excesses as described above. This discrepancy suggests that, apart from the effect of reddening, there is an intrinsic color dispersion which is correlated with luminosity but not with decline rate.
CATA members also performed a study on distance determinations using the Standardized Candle Method for Type II plateau supernovae, using a sample of 37 objects with BVRI photometry and optical spectroscopy obtained by them between 1986 and 2003. Using these data they implemented a procedure to fit analytic functions to the light curves, color and expansion velocity curves. Then they demonstrated that the V-I color toward the end of the plateau phase can be used as a good indicator of host-galaxy dust reddening and we recovered the luminosity-velocity relation previously published in the literature. Using this relation and assuming a standard reddening law they obtained Hubble diagrams with a dispersion of 0.4 mag in BVI. Leaving Rv as a free parameter it was found that the dispersion decreased to 0.25-0.30 mag, which implies that these objects can deliver distances with a precision of 12-14%. The resulting value for Rv was 1.4, which suggests a non-standard extinction law along the line of sight toward these supernovae.

In 2010, researchers of Area 6 began a new collaboration with the Araucaria Project group at U. de Concepción with the purpose of calibrating the luminosities of nearby supernova using Cepheid distances. The first result, published in 2010, is a paper reporting the distance modulus to NGC 7793 of 27.68 ± 0.05 mag (internal error) ± 0.08 mag (systematic error), which is the host galaxy to SN 2008bk. This Cepheid distance will allow them to calibrate the optical/near-infrared light curves obtained by us during the first two years of the evolution of SN 2008bk, a very interesting object similar to the sub-luminous Type II P SN 1999br.

2. TECHNOLOGICAL INNOVATION

CATA has supported several initiatives of its members at the different Associated Institutions concerning technological innovation. In what follows we provide in detail the work and progress made during this period in the three main technological initiatives.

AREA 7: Astronomical Instrumentation
P.I.: Leonardo Bronfman

ALMA BAND 1 PROTOTYPE RECEIVER CONSTRUCTION

The foundational project of CATA in Astronomical Instrumentation is to develop an ALMA Band 1 receiver prototype and study the feasibility of producing 66 operational receivers for the ALMA Project, the largest array telescope in the world, consisting of 66 antennas, each housing 10 low-noise receivers in different bands between 31 and 950 GHz. The Band 1 receiver, covering the 31.3 - 45 GHz range, is being developed at the Millimeter-Wave Laboratory of the Astronomy Department, in collaboration with the Electrical Engineering Department, both at the Universidad de Chile. The Band 1 receiver is a dual polarization Single Sideband SSB receiver. The noise temperature is aimed to be 17 K over the central part of the band. The IF output covers from 4 to 12 GHz with a power variation less than 6 dB. The RF signal is coupled into the receiver by a horn and a lens. Two filters prevent IR radiation to heat the optics. After the horn the signal is split, by an OMT, into two signals with perpendicular linear polarizations, each processed by separate receiver chains driven by the same LO. In the first stage the signal is amplified by a cryogenic LNA, with 30-35 dB of gain. A compact isolator between the LNA and the down-conversion system permits a relaxed specification for the output return loss of the amplifier. Before the mixer a high pass filter cancels the image frequency, having in this way an upper sideband (USB) conversion scheme. The down conversion process is carried out by a commercial Schottky mixer. Finally, the IF signal is amplified by an LNA at room temperature

In 2008 Dr. Patricio Mena, formerly at SRON, was hired by the Electrical Engineering Department as Assistant Professor, and became involved in the project. Two major pieces of equipment were purchased to set up the Millimeter-wave Laboratory at the National Astronomical Observatory in Cerro Calán; a high sensitivity Vector Network Analyzer and a high-precision Computer Numerically Controlled (CNC) Drilling and Milling Machine. A preliminary design of the receiver was produced, and electromagnetic modeling of several parts was carried out. A mechanical technician, José Pizarro, was hired and trained. A preliminary physical layout of the receiver was completed in 2009 and the key components specified. Construction of key optic components was carried out in the laboratory machine-shop, including the receiver feed horn and the Ortho Mode Transducer (OMT). A beam scanner for measuring the horn pattern was built and implemented. A first Low Noise Amplifier (LNA), based on commercial GaAs chips was designed, built, and tested at the laboratory.

Cryogenic capabilities were set up in 2010. A NAOJ Cryostat (for ALMA cartridges testing) was set to work, and a CBI Cryostat was modified for component testing. The horn was successfully characterized using our beam scanner; the OMT design was improved; a series of LNAs based on MMIC was produced improving our knowledge of the fabrication process. The optical design was completed and an analysis of the different alternatives was done in collaboration with HIA. For the design of the complete receiver, the internal dimensions of the main components were defined, allowing a detailed design of the receiver.

Status of the Receiver Prototype.

Optics

OMT: The OMT was designed following a model by H. Asayama which has been successfully used in ALMA bands 4, 5 and 8 receivers. After several iterations an improved and final version was obtained. The measurements for transmissions and reflections corroborate that this design achieves ALMA specs regarding cross-polarization and crosstalk. We fabricated a second version of the OMT to test reproducibility of fabrication. Both OMTs present similar performance.
Horn: We designed a spline-line corrugated horn and constructed using a split-block technique. The near-field beam-pattern setup has been improved and used to obtain a final test of the horn. These results were published in our first ISI article.
Lens: A theoretical analysis of the quasi optical beam propagation between the secondary mirror, lens, filters and horn was completed. A first version of the lens was designed at the lab; then machined at the University of Koln; and finally tested successfully at the lab. A second version will incorporate an antireflection pattern in its design, and measurements are underway to refine the models.

Amplification and down conversion

LNA: Preliminary calculations indicate that the optics will have a contribution of around 7K above the noise temperature of the receiver. Considering this, the specification for the LNA is a noise temperature of 17 K over 80% of the band. This noise specification is comparable with the state of the art Q Band LNAs, but Band 1 has a wider bandwidth (36% instead of 20 % of the central frequency). A review of the specifications for Band 1 and some proposed technologies were presented in international meetings. We have finalized our initial project, packaging commercial MMICs amplifiers, with 3 amplifiers characterized. Gold plating of the final unit was achieved in association with local industry. To reach the specifications of ALMA Band 1, we have focused on the design of hybrid amplifiers based on InP transistors (obtained from JPL-CalTech), which promise to achieve state-of-the-art performance. While a lot of effort has been done to realize this design, more work is required to achieve this implementation. The main hinder is the construction of the waveguide-to-stripline transitions, as both the technology and the materials for these frequencies are novel in Chile. We have learned several lessons and are implementing them in a second version of the amplifier packaging. The new version will use a different substrate material for the waveguide-to-stripline transitions, namely Si instead of Cuflon, that has already been ordered to a US company.
Isolators: The use of isolators is indispensable. We identified a company that provided four isolators, optimized for low-temperature operation. These isolators have been characterized in the component test set-up, giving acceptable results.
Mixers: A commercial mixer has already been purchased and tested. While its performance is marginal for the project, it can be used in the first prototype. In the meanwhile we have identified other commercial options that will be purchased and tested next year.

Cartridge Assembly

Lens and Horn: The horn and lens were mounted and tested in our beam-pattern setup. The results validate the original design, the only remaining issue being the antireflection pattern.
Mechanical and Electrical Assembly: The first mechanical design is completed (Fig. 4). The support structure (namely the ALMA blank cartridge) has been built in collaboration with a local company. The commercial elements, like DC bias connectors, RF feed-through connectors, and temperature sensors, have been purchased; the electrostatic discharge protection (ESD) card is being designed and will be built at DIE; and the full assembly will begin in Q1 2012.

Cartridge Optical/Cryogenic Test Setup

The ALMA cryostat purchased from NAOJ is performing to specifications in the lab. An adapter to incorporate the lens in the cryostat was designed in house and built by a local company. The cryostat, adapter and lens were successfully assembled, and no vacuum leaks were found. The heat filters at the different cryogenic shields have been already procured and will be mounted soon. An engineer was hired to implement the optical/cryogenic test setup to characterize the receiver mounted in the NAOJ cryostat. Fully compatible control electronics were purchased from NRAO, allowing measurement to be performed in an ALMA compatible environment.

The goal for 2012 is to mount the first receiver and test its performance in the laboratory. This will require finalizing all the described sub projects. The LNA design is the only component that might need more time to achieve the ALMA specifications. The first receiver will be tested preliminary using the already built MMIC amplifiers, to test the complete receiver and its components. The work on LNA will continue during next year and probably beyond, as it is still an open field of research.

In summary, the prototype development is well underway. During this year, we aim to have a receiver cold cartridge assembly (CCA) unit operating at the laboratory, with its optical and electrical properties characterized with an in-house cryogenic set-up. The process is requiring lots of research, laboratory development, and mastering of several technologies that are new in the country. We have been particularly successful in the development of the receiver optics, presently up to ALMA standards, and our anechoic chamber is a unique facility in the country. The design of the cartridge is ready. Several parts, including the blank cartridge assembly (support structure) are built, while mounting and wiring is ongoing. The cryogenic test set up to characterize the receiver at cold temperature is designed and an engineer is working in its implementation.

One of the most important technologies, low noise amplifiers, is still developing world wide to meet the specifications from ALMA. Our strategy is to characterize and pack high performance transistors from CALTECH –JPL into an amplifier at the laboratory. We have preliminary packed commercial components, and realized that it requires mastering intermediate techniques, each with specific timescales, which could indeed be improved with the addition of new equipment.

Based on the work already executed, we should be able to study the feasibility of producing the full suit of receivers in Chile. Crucial for this is to evaluate what has to be outsourced to local industry and whether it is possible for industry to meet the challenge. The Continuity plan for CATA should therefore contain the description of the prototype plus a feasibility study for production, including the interaction with technology providers and local industry. An important goal for the second period of Basal would be the transfer of technology.

While the design of our prototype is ready according to ALMA specs; the CCA is under construction and should be ready by 2012; and a state-of-the-art LNA construction should materialize via our collaboration with Yebes, the astronomical requirements for the receiver are being re discussed by the ALMA community to raise the upper limit of the Band 1 up to 50 GHz. While not fully decided, inclusion of such frequency extension in our design would certainly increase our ability to be considered as a suitable provider. Two years of development are estimated to accommodate the extension. This is also about the time needed to build the WCA (warm cartridge assembly), with the goal of producing a fully operational ALMA receiver by the end of 2014, and be ready for pre-production of more units. It is roughly the time scale for maturing of the ALMA development plan, and to start planning construction of a full suite of Band 1 receivers.

AREA 8: High performance computing
P.I.: Alejandro Clocchiatti

The Computing Lab (CL) of the Center for Astro-Engineering (AIUC) at Campus San Joaquin of Pontificia Universidad Catolica de Chile (PUC) started as a concept by the turn of the century. This was motivated in part by the projects of wide angle survey telescopes that were going to be installed in Chile, with the promise of delivering very massive amounts of data, and in part by the need of theoretical astrophysicists who require massive computational power to model a given survey, or the evolution of astrophysical objects. The concept started to become a reality with the approval of CONICYT Basal project CATA in December 2007, which invested 30% of its funds for large capital investment in the computer for the CL. This document is a description of the advancement of the project, the difficulties and successes within the period. In what follows, we will call the computer by its designated name: Geryon.

Putting Geryon to work involved several steps which involved identifying the appropriate machine, to buy it, to construct a computer room, install the machine, test operating and qeue systems, install the software suites, and to try and test-bench the computer. The first applications envisioned were both observational and theoretical, and the new computer immediately allowed us to enter scientific grade development and number crunching locally, experiment with queues and, finally, open the system to the whole community.

Putting the CL to work consisted on using Geryon to run software built by several consecutive generations of researchers, with contributions from our own people, taking advantage of the capabilities of the computer, and using this to motivate the connection between observational and computational astrophysicists with computer science specialists, and to develop new software for theoretical and observational research. This required, in addition to the computer, a focus on hiring Computer Scientists with interest in Astronomical applications and establishing the necessary collaborations.

As a result, the CL has already acted as a consultant for the computing industry in Chile. The experience developed by the engineers and technicians that set up Geryon has been required by other public and private institutions that were following our steps. Therefore, in addition to providing a unique computing service to the astronomical community, the CL has contributed to capacity building within the Chilean academia and industry.

First steps: Purchase and Installation of Geryon

This computer was the first piece of equipment in its price category acquired for Chilean astronomy. Following the guidelines for the grant, we opened a call for bids in October 2008 after we were transferred the funds. To do this we defined the profile of the system we required. A strategic decision was to stay with the hardware we had in our pre-Geryon machine (with 24 Quad Core Intel Xeon 2.0 GHz processors). We proposed to purchase 96 CPUs, each 4 cores, each core with 1GB of RAM, for a total of 384 GB of RAM, 13 TB of iSCSI disk, three 10 KVA UPSs, Gigabit Ethernet equipment and a 19" rack. To facilitate the bidding, and give room for more companies to enter the call, we divided the purchase in three packages that could be proposed for independently:

1. CPU's, network equipment, casing, cables and accessories.
2. 3x10 KVA UPSs.
3. iSCSI Disk of 13 TB.

We received the equipment in March 2009, which was installed by April 2009 in a temporary computer room. In May we started trials on the base of an open source Linux OS with 64-bit architecture. Pretty soon the machine was equipped with the required tools: Intel FORTRAN and C compilers, a Distributed Resource Management suite, and the Sun Grid Engine. In June, Geryon started operations. At the time, it was the most powerful machine for exclusive astrophysical use in Latin-America.

The new building for the AIUC and the CL was finished in February of 2010. Additional funding from the Departamento de Astronomia y Astrofisica of PUC allowed us to purchase a professional grade AC system and an additional power transformer to warrant a safe power supply for the machine. Geryon was fully installed in its definite place by April 2010. The event was celebrated with a workshop "Supercomputer Techniques in Astrophysics," which brought many specialists from around the world to our campus.

During the following months the system was tested thouroughly, and several small grants from different researchers were joined to achieve the expansion of the memory to the necessary 1TB of RAM for a total of 2Gb per core. The computer power of the system was 2 TFLOPS.

By the second semester of 2010 we announced the opening of the system to the whole Chilean astronomical community. A protocol was established to access the resource and from this point, the prospective users submit their requests for time according with instructions available on the web, and using a downloadable LaTeX form. For runs that require more than 6000 core hours per month, a local TAC evaluates the request within 10 working days. These jobs are scheduled in special blocks during the nights and weekends whereas smaller jobs are run freely in the remaining cores. Geryon has been continuously upgraded. Different projects and users contributed in a coordinated way different pieces of hardware. The system now has a front-end of 64 bits, a hard drive of 4 TB for users and their accounts, 40 TB of iSCSI disks, and ~ 60 TB of other disks for special projects.

In summary, CATA was successful in establishing the CL area as a community resource. The CL now hosts Geryon and some other independent (smaller) machines which are ran by the same technical team. Several lines of science have already been developed with Geryon. Many of them fall within the original lines of the project, and new ones arised as the result of new scientific drives which are now possible thanks to the available computing power. Four students have already gotten their Ph.D. with work based mainly, or significantly, on Geryon. All of them accepted postdoctoral positions abroad. At present, several students at different levels are intensively using Geryon.

Given that the computing power of new computers already outrun the individual CPUs in Geryon, we put in a grant proposal to purchase a major piece of equipment in November 2011, which was awarded by the end of the year. With these funds we will be able to buy a new system which will represent a 10 fold increase with respect to our present capabilities. A challenge for Chilean astronomers is to be able to use the first world instrumentation we have access to, and this means matching resources for analysis and modeling. CATA CL is a proof that we can do it.

3. FORMATION OF HUMAN RESOURCES

3.1 Graduate students

CATA is strongly and continuously supporting the formation of human resources in astrophysics in all of the Astronomy programs in the country. During the last four years the number of graduate astronomy students at the three institutions associated to the Center experienced a considerable growth. In the four year of operation (2011) there were fourty nine (49) Ph.D. students in astronomy and thirty three (33) students in Master's in Astrophysics programs, with a total of 82 graduate students. Most of the graduate students have taken advantage of the Center by being granted funds in order to participate in observing runs at the International Observatories in Chile and/or to attend international meetings. In addition the Center has given full fellowships to more than sixty of the graduate students.

The Key projects are having a big impact on the graduate programs since they broadened the range of thesis topics and giving the students the possibility of engaging in first-class frontier research. In fact more than fifty percent of the graduate and undergraduate students have worked or are working in individual science projects associated with Key Projects. During the four years of operation twenty three (23) students obtained Ph.D. degrees and thirty four (34) students obtained Master degrees. Most of the later continued their high learning education at top North-American and European universities. In addition, a few dozen students obtained their undergraduates diploma (Licenciaturas).

In order to educate the new generation of astronomers, CATA continuously supported the delivery, at their associated Universities, of Mini-courses with the goal of training graduate students on specific topics. The Mini-courses consisted of five to ten lectures given in a period of 2-3 weeks, in order to allow the presence of invited lecturers from abroad, and were open to all graduate students of the different astronomy programs in the country.

3.2 Postdoctoral Fellows

The Center provided the funds and visibility necessary to attract young scientists from all over the world. Most of the postdoctoral positions were selected through international competitions, and we hired postdoctoral fellows from Argentina, Australia, Brazil, Bulgaria, Germany, Italy, Mexico, Poland, United Kingdom and USA. With the presence of these postdocs the CATA has gathered a real international team working at Chilean institutions. Postdoctoral fellows have been central to the success of the Key projects of the Center, which required lots of manpower in the experimental and analytical work.

3.3 Human Resources devoted to Research

CATA has allowed a substantial increase in the number of researchers and engineers working at all three Associated Universities. Fourteen (14) new researchers -- ten astronomers and four engineers -- have been hired with the Center support and received continuous support for their scientific activities. In the following we give the names of the new researchers, the year of incorporation to the Center, their areas of research and the University in which they were hired (UCH: Universidad de Chile, PUC: Pontificia Universidad Catolica, UdC: Universidad de Concepcion) :

Escala, Andrés	2008	Theoretical Astrophysics, Black Hole Mergers, Star formation	UCH
Jordán, Andrés	2008	Early-type galaxies and their globular cluster systems	PUC
Mena, Patricio	2008	Electrical Engineer	UCH
Vanzi, Leonardo	2008	Engineer	PUC
Altamirano, Pablo	2009	Engineer	UCH
Bauer, Franz	2009	AGN Demographics; Super-Massive Black Holes	PUC
Cuadra, Jorge	2009	Theoretical Astrophysics., Gas dynamics, Massive Black Holes	PUC
Demarco, Ricardo	2009	Galaxy formation, Cluster of galaxies	UdC
Dünner, Rolando	2010	Formation and evolution of super-clusters of galaxies	PUC
Fellhauer, Michael	2009	Numerical simulations of stellar dynamics in galaxies	UdC
Bustos, Ricardo	2010	Enginner	UdC
Puzia, Thomas	2010	Star clusters, galaxy formation and chemical evolution	PUC
Muñoz, Ricardo	2011	Evolution of dwarf galaxies and Galaxy interactions	UCH
Treister, Ezequiel	2011	Active Galactic Nuclei	UdC

The new faculty positions were made through international competitions, which attracted a large number of outstanding candidates from all over the world willing to come to Chile.

In addition, the Center supported selected researchers at other Universities in Chile in order to increase the scientific collaboration with their new astronomy groups. The Center provided them with funds for travel and expansion of human resources, in particular for the hiring of postdoctoral fellows with research interests close to those of the Key projects. S. Sharma and R. Muñoz were hired at Universidad de Valparaiso and G. Gunthardt and M. Soto were hired at Universidad de La Serena. The researchers from other Universities that became associated to the Center are:

- Rodolfo Barba, Universidad de La Serena
- Jura Borissova, Universidad de Valparaiso
- Veronica Motta, Universidad de Valparaíso
- Giuliano Pignata, Universidad Andres Bello
- Matthias Schrieber Universidad de Valparaiso

4. NATIONAL AND INTERNATIONAL COLLABORATION

In this section we briefly specify the activities conducted by CATA during the 4 years of operation that contributed to the networking at National and International levels, and at Institutional and personal levels.

Collaboration among Center members of the three participating institutions have taken place in all the areas of research, amply fulfilling one the scientific goals of the Center. The Center Key Projects, which were implemented to foster collaborations between researchers of the different astronomy sites within the country, developed quite successfully. They received considerable amounts of telescope time, allowing Center members to carry out scientific projects that were beyond the scope of small research groups. The most emblematic Key Projects with respect to collaborations, involving more than 10 researchers from the three associated Universities, are the MUltiwavelength Survey by Yale-Chile (MUSYC) and the Vista Variables in the Via Lactea Survey (VVV).

Thirty percent of the refereed papers that were published during the ten year period have two or more Center members as co-authors. The scientific collaborations between Center members increased continuously in time and have produced results of considerable impact. The degree of collaborations, measured from published ISI papers, increased from nine eight (98) during the first year of operation to a value of two hundred and fourteen (214) during the fourth year of operation, indicating that joint work has more than double during the period.

In particular, there are numerous collaborative contributions between researchers of Areas 2 and 3, including the work on chemical abundances of Milky Way Cepheids which helped to measure the metallicity gradient in the MW disk, the first determination of the element abundance gradient in the disk of a spiral galaxy beyond the Milky Way using blue supergiant stars in NGC 300, and the first empirical demonstration of strong population effects in red clump stars in optical bands. Another example of synergy, involving researchers of Areas 3 and 6, is the Cepheid distance determination to the Sculptor Group spiral galaxy NGC 7793 which hosted SN 2008bk. The synergy was also strong between researchers of Area 5 and researchers of Area 2 and Area 3, with common publications taking advantage of similar techniques (e.g. precision photometry, optical spectroscopy). Another example of synergy is the on going project of characterisation of extrasolar planetary transit candidates, involving scientists from the three associated Universities.

The Center also invited world experts on different astrophysical topics. The contribution of the visiting scientists has been remarkable, supplying the expertise needed for an expansion and broadening of the areas of research cultivated at the Center, and providing the theoretical support needed in the young Ph.D. programs. They usually give concentrated courses, during periods of 3 to 6 weeks.

IV. ALLIANCES

Indicate in no more than **4** pages which are the most valuable alliances of the Center with public /private, national/international partners. Describe what their advantages for the outcome of the Center have been or you expect to be in case of continuity of this project. Describe also whether initially well-aspected alliances have not resulted into expected development.

The newest and most valuable alliances of the CATA Center have been established in the areas of technological development, both with national and international partners.

The mm-wave laboratory, in the pursue of its main goal of constructing a receiver for Band 1 of ALMA, has established collaborations with several institutions around the world which are leaders in the manufacturing of different parts needed to build a receiver. Among the most important alliances we mention the following:

- Collaboration with the University of Manchester in the design of low noise HEMT amplifiers using advanced technologies.

- Collaboration with the Mechanical Engineering Department at U. Chile to produce a dynamical simulation of the cartridge.

- Collaboration with Centro Astronómico de Yebes in the construction of state-of-the art Q-Band LNAs based on MMICs; the novel plan consists of using a low-noise transistor in front of the MMIC. Also to accelerate our ability and produce a competitive and repeatable amplifier, we collaborate with Observatorio de Yebes, an important supplier of IF amplifiers to ALMA. A PhD student, with two years in our lab, is spending a semester there, with the goal of building an amplifier based on new technology developed recently by Fraunhoffer Institute.

- International collaborations with the Herzberg Institute for Astrophysics (HIA Victoria) and with the Academia Sinica (ASIAA- Taipei), Taiwan have been established. A large interest has recently arisen from HIA and ASIAA, in developing Band 1. While HIA is pursuing the full process, ASIAA is oriented to the development of components, principally amplifiers. We have collaborated with them since 2008, including monthly VCs and annual meetings. Common development has successfully occurred with HIA in the receiver optics, horn and OMT. There is full and mutual exchange of information about receiver components and technological advances, with the spirit of presenting the construction proposal as a consortium. However, because of the yet undecided mechanisms for ALMA to procure the Band 1 receivers, it is not possible to plan this in detail at present. Therefore we should keep increasing our abilities to play a leading role and reinforce our participation in such consortium. In agreement with HIA and ASIAA, the document "Band 1 Cartridge Technical Specifications" was completed, including the definitions of the interfaces with other ALMA subsystems.

Our strengths, in relation to our collaborators, are that (a) we have already designed a complete system of the prototype cartridge, now under construction, and have the ability to assemble such prototype in-house; (b) we have completed the construction of the optics components, and are working in the second version of the lens; and (c) we have an ALMA compatible cryostat to test the receiver cartridge. Our weaknesses are (a) the lack of a more practical cryogenic set-up to test components, specifically the amplifier; (b) the lack of a spectrum analyzer for testing the final receiver; and (c) the lack of a probe station to mount and test the individual amplifiers. The first item is planned to be built in 2012; for the last two, we requested, at the end of last year, the needed equipment to the FONDEQUIP program and got the proposal approved.

The High Performance Computing Lab (HPCL) was born with CATA funds in alliance with the Center for Astro-Engineering (AIUC) of Pontificia Universidad Catolica. The HPCL is located within a new building hosting the AIUC and the HPCL was finished in February of 2010. Advancing the HPCL means expanding the knowledge in the Computer Science area. Regarding this CATA was able to negotiate with the School of Engineering of PUC, where a new position in the Computer Sciences Department was opened to carry out research in astrophysics with Geryon.

V. PARTICIPATION OF COUNTERPART FUNDS

Considering that the Center functions with Basal Funds as well as other sources, please, indicate briefly how the overall performance of the Center (and not only the Development Plan of this particular project) lies on different sources of funds, public or private, national and international. For example, is student training something that may be funded better by another source than this? Does the private sector contribute to the development of particular activities of the Center? Are different fund sources necessary to finance certain activities since those funds in isolation are not enough?

The main partners to operate CATA are the three associated universities: Universidad de Chile, Pontificia Universidad Católica and Universidad de Concepción. They provide most of the infrastructure where the CATA activities take place and share operational costs and salaries of researchers, support personnel and students. There is a strong symbiosis between the Universities and CATA. Without CATA, astronomical development at the Universities would have been minimal. Without the Universities, CATA would have had much less impact in its scientific output and in the technological development.

In addition to the contributions from the host institutions, CATA members have accreted important resources from competitive national funds (Fondecyt projects and Milenium Nucleus) as well as from international astronomy funds (ALMA, GEMINI and ESO). The national funds are mainly devoted to travel support, to the renewal of computer equipment and to pay page charges. The extent that these resources cover the actual need in these items is variable and depends on each project, but often CATA has to contribute towards the same objectives because their funds are not enough. With respect to the competitive international funds an important fraction of the granted resources have been devoted to buy new equipment very much needed at the CATA laboratories in order to achieve the goals in the technology areas.

The activities undertaken by CATA have established the fertile ground for its scientific personnel to successfully apply to other sources of funds that enhances the objectives of the Center but their contribution to the running of the Center is limited. All of the above mentioned funds, including the contribution from the host universities, are tied to a particular purpose and cannot be use in other ways. Basal funds are thus not only crucial in providing a large fraction of the needed resources but also are important to run the Center with the flexibility necessary to move in the best direction to achieve our final goals.

VI. APPLICATION OF THE RESEARCH RESULTS INTO ACTIONS THAT CONTRIBUTE TO INCREMENT THE COMPETITIVENESS OF CHILEAN ECONOMY (INDUSTRY, CIVIL SOCIETY AND PUBLIC BODIES OR POLICY MAKERS)

In no more than **15** pages, use this section to describe the way the Center activities and/or results of the implementation of the development plan have allowed approaching to public and/or public entities. Refer to aspects like technology transference, licensing, use of particular know-how, and other initiatives (e.g. alliances, growing, diversification, spin-offs). Also, describe the way in which the impact of a determined expertise has influenced the amount of invitations or participations of members of the Center in commissions/committees or other instances of decision and/or consultation in the development of public policies.

Comisión Nacional de Investigación Científica y Tecnológica - CONICYT

VII. OUTREACH AND DISSEMINATION

This section should be written in no more than **5** pages and must describe the most relevant and significant events of the whole period and their possible continuity. Refer, also, to the interaction with communities either public or private entities where an

instance of specific effective collaboration with or without future perspective has been settled.

AREA 9: Outreach
P.I.: José Maza

CATA has carried out a vigorous policy of education and public outreach, implementing many initiatives on Education and Public Outreach. CATA has funded important activities directed to the general public, high-school students and their teachers. Among the main activities implemented and supported by the Center we mention the followings.

Popular Science Books.

One of the highlights in outreach of CATA was the creation of a series of four popular science books written by Center members targeted for high-school students and educated general public. The booklets, published by Ediciones B, are:

- "Hijos de las Estrellas" by María Teresa Ruiz
- "Mundos Lejanos" by Dante Minitti
- "Con ojos de Gigantes" by Felipe Barrientos and Sebastián López
- "Supernovas" by Mario Hamuy and José Maza.

The booklet by María Teresa Ruiz has sold more than 5,000 copies (three editions 2,000 copies each), a remarkable and unexpected achievement. The other three have also been received with great appraisal and sold some 2,500 copies each. In total some 12,500 copies has been sold. The International Year of Astronomy along with the many popular lectures offered by the authors during 2009 are responsible for the editorial success of the series.

Center member José Maza prepared and published a new edition, by "Ediciones B", of his introductory astronomy book "Astronomía Contemporánea" written for high school children, which was originally published in 1988 and out of print for at least a decade. In the first two years the book sold 1,700 copies, an excellent number for the Chilean book market.

By the end of the 2009, Center member María Teresa Ruiz published a popular book in astronomy which in addition to astronomical images and explanations contains poems by Margarita Schultz. Entitled "Voces del Universo /Voices from the Universe" it was published by "Ocho Libros Editores Ltda" in a bilingual edition Spanish/English. It was released in January 2010. Presented in a big format it is a beautiful "Coffee Table Book".

María Teresa Ruiz, in collaboration with Margarita Schultz, wrote an innovative book of astronomy designed for children aged 8 to 14 entitled: "EL Universo: Ciencia y Ficción. ¡Qué (no) te cuenten cuentos!", published by Confin Editores at the end of 2011. The book has been celebrated as an excellent addition to the popular science books for children. The book was presented at the Observatory at Cerro Calán and many people attended including former President of Chile Mr. Ricardo Lagos, President of the Senate Dr. Guido Girardi and Vice-President of the Senate Mr. Juan Pablo Letelier.

Training of high school science teachers.

During 2010 high school science teacher Víctor Salinas was hired to analyzed basic school and high school science curriculum relative to astronomy. He then prepared material to train science teachers in astronomy. PhD student Paula Lopez was responsible for preparing part of the content.

The training of teachers is carried out at Cerro Calán Observatory. Teachers coming from all over the country, with the support of CATA, gather for a week at Calán where they receive lectures, practical sessions, observing sessions and a large quantity of material including a special booklet printed for them. So far fifty science teachers, coming from Arica to Punta Arenas, have been trained in two workshops. In addition we created a facebook "Astronomia Educativa 2.0" where all science teachers that have attended the workshops are participating and sharing experiences.

Astronomy in Public Schools.

For visits to high school students and to grammar students Center members prepared power point presentations and small booklets, 16 pages long each, containing the material of the lectures.

During 2010 CATA implemented an outreach program, called *Project Carina*, with the goal of spreading astronomy in public schools in the (poor) neighborhoods of Santiago. Three portable telescopes were purchased, – two Schmidt Cassegrain of 8 inches and a refractor of 4 inches of aperture – which are used for star parties at the different schools. Science teacher Victor Salinas delivers lectures during the week and on Friday evening we take the portable telescopes to the schools to have a star party with the students and their parents. The project included Puente Alto, San Bernardo, Curacaví, María Pinto, Melipilla, Lampa, Rungue, Huertos Familiares, etc. For this project we hired Edgardo Cosgrove a high school science teacher with experience with telescopes – he worked at Cerro Tololo Inter-American Observatory for three decades as night assistant - to operates the telescopes of *Project Carina*. So far 1,570 students have attended the lectures and parties. On every school visited two astronomy books were given as a present for the library.

During 2011, CATA contacted "Corporación de Desarrollo Pro Til Til" y "Corporación de Desarrollo Pro Aconcagua" in order to develop a project at Til Til and another at Aconcagua oriented to students of 4^{th} to 8^{th} year in basic schools (kids in the age range 9 to 13). Two different projects were presented for funding to EXPLORA CONICYT and both were approved for 2012. EXPLORA is funding them at the level of US$25,000 each and Pro Til Til and Pro Aconcagua at the level of US$7,000 each. In addition the car company SUBARU is supporting both projects by lending a vehicle SUBARU Forester2 at least for year 2012 and 2013. Both projects add up to 100 trips to localities some 50 to 80 miles north of Santiago.

VIII. DEVELOPMENT AND IMPLEMENTATION OF INFRAESTRUCTURE

The following section should provide information about the uses, advantages and services related to the development and implementation of infrastructure as well as the results in terms of collaboration, or others.

After CATA was funded by CONICYT, all three Institutions associated to CATA decided to invest considerable amount of resources in infrastructure in order to allow the development of instrumentation in astronomy in Chile, one of the goals of CATA.

Millimeter Wavelength Laboratory.

Universidad de Chile built at Cerro Calán Observatory, during 2008, a millimeter wavelength (mm-wave) laboratory, led by Professor Leonardo Bronfman, where CATA members could carry out the development of receiver technology. The need for a mm-wave laboratory arises from the installation of the world's largest sub-mm-wave telescope in Chile, the ALMA telescope, which presents a tremendous opportunity for the education and training of qualified personnel to support the development of engineering and of astronomical instrumentation in the country. The mm-wave laboratory is serving as a hands-on training for Chilean engineers and graduate students specializing in astronomical instrumentation. This laboratory is carrying out state-of-the-art projects in astronomical instrumentation, focusing on receiver development, in collaboration with recognized institutes (e.g. California Institute of Technology, ESO, University of Cologne, Harvard-Smithsonian Center for Astrophysics, Chalmers University of Technology). The goal is to boost the local development of the technological ability to design and construct receivers.

The mm-wave laboratory is also implementing at Cerro Calán a 1.2 m radio-telescope, operating in the 86 – 115 GHz frequency range. Modernization of the telescope receiver is underway to optimize its scientific operation. Technological innovation is achieved by building state-of-the-art equipment; two projects are ongoing: the first, upgrading the receiver for side band separation, increasing its sensitivity; the second, building a digital spectrometer with high band-width and resolution. The work is performed by Electrical Engineering PhD students from the Astronomical Instrumentation program.

High Performance Computing Laboratory.

Pontificia Universidad Católica created, during 2009, the Center for Astro-Engineering (AIUC) to host the High Performance Computing Lab (HPCL) and to exploit the scientific and technical activities between Astronomy and Engineering, becoming a joint venture between the Astronomy Department and Engineering. The HPCL is aimed at providing to CATA members the required computational capabilities to deal with the data acquired with the new mega-facilities and as well as to perform numerical simulations. AIUC is led by Professor Leopoldo Infante. The mission of the AUIC is to foster the collaboration of astronomers and engineers around three main research areas: astronomical instrumentation, astronomical computing and astronomical services. The Center aims to exploit its privileged location in Chile to make significant contributions to current and future astronomical projects and to promote technological transfer between the international observatories and local academics and industry. In what follows we list the main projects that have been or are being carried out at the Instrumentation Laboratory of AIUC and their achievements.

Instrumentation Laboratory.

• AIUC developed the design and later built PUCHEROS. This is a high resolution fibre fed spectrograph for the visible spectral range. The instrument was completed and installed at PUC´s observatory Santa Martina at the beginning of 2011. In mid 2011 the instrument started regular operation being offered internally at PUC, at the national and international community. Besides being used by several scientific projects, the instrument is used by students within their advanced courses of astrophysics and for their projects of research. To our knowledge PUCHEROS is the first and so far only entirely Chilean instrument which is currently in operation.

• AIUC is co-investigator in a proposed instrument for the Giant Magellan Telescope (GMT). This instrument, dubbed the "GMT-CfA-Carnegie-Catolica-Chicago Large Earth Finder" (G-CLEF) is a high resolution, fiber-fed, highly stabilized optical echelle spectrograph that will be capable of measuring radial velocities with a precision of 9 cm/s. It will have three modes that will allow it to address science cases such as stellar archeology in the Milky Way with measurement of chemical abundances in faint stars and the search for Earthlike planets in the habitable zones of Sun-like stars. The instrument went through a preliminary design review in September 2011 and is very likely to be selected as a first light instrument for the GMT. The AIUC will design and build the two cryogenic cameras, each comprising a 6k x 6k CCD detector.

• A laboratory has been created, dedicated to teach and research in CCD detectors. AIUC focus on the design and fabrication of cryogenic cameras for astronomical instruments, running scientific CCDs and NIR detectors.

• Research is being carried out in wide-field adaptive optics, with the goal of building an optical bench to investigate a number of areas in AO required to implement Multiple Objects Adaptive Optics (MOAO) in Extremely Large Telescopes. Various research activities are ramping up: Wide-field Adaptive Optics; Multi-Conjugate Adaptive Optics; Beam shaping for Laser Guide Stars; and Cn2 characterization.

•Astronomical “Site Testing”, (sub)mm, radio and optical and Telescopes performance evaluation are part of the AIUC activities. Particularly, Center members work for the Atacama Cosmology Telescope (145, 220 and 280 MHz) in El Toco. The AIUC team performs the tests and characterizes the main reflecting surfaces of the telescope.

Astronomical Services.

• The AIUC has partnered with the Harvard-Smithsonian Center for Astrophysics in order to provide support for the f/5 instrumentation at the Clay telescope in Las Campanas (Megacam and MMIRS). The f/5 instruments are mounted each semester for approximately two month periods during which specialized support is required. An AIUC engineer has as part of his job to provide such support in close coordination with LCO and CfA staff.

• The AIUC has signed an agreement with the German MPIA to provide astronomical support at the 2.2m telescope at La Silla Observatory.

IX. UNEXPECTED OR UNANTICIPATED OUTCOMES (IN ANY OF THE PREVIOUS ASPECTS)

In this section add any other results or situations that you detected regarding activities of the reported period.

Unanticipated new projects

1.- ALMA Band 5 pre-production and full production study.

The mm-wave laboratory is involved in the assembly, integration, and verification of 6 receivers for the Band 5 of ALMA (186-211 GHz), through a collaboration with an UE-FP6 program that includes ESO, GARD (Sweden) and RAL (UK). While our original participation focused on the training of Chilean engineers, the development of laboratory facilities allowed us to design and build the Beam Scanner Test source (BeaSTS) to measure the receiver beam pattern. A high precision waveguide probe was machined at home, the highest frequency emitter ever built in a Chilean laboratory. Presently we participate of a full production study, having constructed in 2011 the Mixer Block and OMT prototypes.

2.- Side-band separating mixer for ALMA Band 9

Center members are collaborating with the Netherlands Institute for Space Research (SRON) in the implementation of a new sideband-separating receiver for ALMA Band 9 (600-720 GHz). We participated in the design and successfully fabricated, until 2011, three units of the split block that contains the RF waveguide circuitry of the receiver. The waveguides have transversal dimensions with details reaching dimensions of around 20 to 50 microns, the highest precision achieved in a local laboratory. The resulting receiver has been tested at SRON, giving sideband rejection ratio and noise temperature compatible with ALMA specifications.

X. PERFORMANCE INDICATORS

The following section is a summary of the information provided in the previous sections THAT SHOULD COVER THE ENTIRE PERIOD REPORTED. Please, complete the base line and the data for the reported period. When it does not correspond, indicate not applicable with N/A.

Make the changes you do consider that evaluate more accurately the Center dynamics and performance. When including or excluding indicators keep in mind the original base line and those that are mandatory according to the contest guidelines (mandatory indicators are highlighted in yellow).

DEVELOPMENT AREAS	INDICATORS	BASE LINE (*)	REPORTED PERIOD	
			Basal Financing Funds(+)	Other Sources
GENERAL	Number of Principal Investigators	10	10	
	Female Gender (%) of Principal Investigators	10%	10%	
	Number of other Investigators	15	35	
	Female Gender (%) of other Investigators	15%	14%	
SCIENTIFIC EXCELLENCE	Number of ISI publications	70	579	
	Number of non ISI publications	40	319	
	Number of citations in ISI Journals	280	8832	Nota Karl: Valore replicados El valor es cerca de 3000
	Percentage of publications Co-authored with national/international researchers from other institutions	80%	95%	
	Percentage of publications Co-authored with researchers of the Center	20%	34%	
	Average number of citations per article	4	15	
	Number of international exchange networks			
	Number of national presentations/conferences	8	98	
	Number of international presentations/conferences	25	201	

Comisión Nacional de Investigación Científica y Tecnológica - CONICYT

TECHNOLOGICAL TRANSFER AND LINKAGE WITH OTHER SECTORS OF CHILEAN ECONOMY AND SOCIETY	Number of patent applications			
	Number of patent application´s granted			
	Number of licenses and/or Technology Transfer Agreements applied and/or granted			
	Number of spin-offs companies rising from the Center			
	Number of pre & postgraduate students and postdoctorates inserted in the Industrial sector			
	Number of pre & postgraduate students and postdoctorates inserted in other Centers, academic or non-academic, private & public institutions			
	Number of participations in instances of public policy definition (consulting councils, advisory committees).			
	Number of participations in other relevant institutions			
	Number of relevant actions that have a social effect *			
	Amount and % of the Center´s income from private sector companies (in cash and in kind contributions can be considered).	**0%**	**0%**	
	Amount and % of the Center´s income from other non-government sources (in cash and in kind contributions can be considered).		**31%**	**in cash**
TRAINING OF HUMAN RESOURCES	Number of Master students	**24**	**33**	
	Number of completed master theses	**4**	**34**	
	Number of Ph.D. students	**22**	**49**	
	Number of completed Ph.D. theses	**2**	**23**	
	Number of posdocs working in the Center	**18**	**41**	
	Number of undergraduate students			
	Number of completed undergraduate theses			
	Number of stays/visits from students or researchers from other Centers or projects (national and international)	**15**	**81**	
	Number of stays/visits to other institutions by students or researchers of the Center	**20**	**89**	
	Percentage of theses co-tutored with researchers of the Center			
INTERNATIONAL NETWORKS	Number of conjoint projects developed			
	Number of international agreements of exchange with foreign institutions			
	Percentage of ISI publications co-authored with international researchers (from other institutions).	**70%**	**95%**	
	Percentage of theses co-tutored with international researchers from other institutions.	**0%**	**13%**	

SUPPORT TO OTHER RESEARCH GROUPS	% of equipment available to researchers who are not part of the Center.	**0%**	**15%**	
	Percentage of theses co-tutored with researchers from other research groups			
	Percentage of publications co-authored with researchers from other research groups.	**2%**	**4%**	
	Others (please describe)			
OUTREACH ACTIVITIES	Number of times the project appears in mass media.	**0**	**20**	
	Number of documents, reports, proceedings resulting from outreach/extramural events or activities.			
	Number of conjoint projects developed for the purpose of executing outreach activities*			
	Number of outreach and/or extension activities.	**10**	**70**	
	Total number of people attending to outreach and/or extension activities.	**1000**	**8000**	
	Others (please describe)			

*These should be mentioned and/or described in the report text.

(*) Base line is the average indicator from the last 3 years before the application (presented in the Application Form).

(+) Including resources from the Basal Financing Program and resources from other significant and stable public sources, such as: FONDAP, Institutes and Groups of the Millennium Scientific Initiative (ICM) and Regional Center Associations in Science and Technology, Team Research Projects in Science and Technology.

XI. FINANCIAL STATEMENT

FUNDS OBTAINED

Please indicate the funds obtained in the reported period using the following table:

MAIN FUNDING		**Amount (M$)**	**% of total**
Main Public Funding - Significant and Stable			
CONICYT	Team Research Projects in Science & Technology (PBCT) - PIA	3.057.986	40
	Regional Centers		
MSI	Millennium Institutes		
	Millennium Nuclei	1.180.820	15
COUNTERPART FUNDING			
Less Important Public Competition Funds			
CONICYT	FONDECYT	1.080.756	14
	FONDEF		
	INTERNATIONAL COOPERATION		
CORFO	CORFO - INNOVA		
Other, insert rows	*Name of the institution*		
Private Sources - National or International Non-Profit or For-Profit Organizations			
National Sources			
Corporations	*Name of the institution*		
Non-profit Org.	*Name of the institution*		
Other, insert rows	*Name of the institution*		
International Sources			
Corporations	*Name of the institution*		
Non-profit Org.	ALMA	1.114.814	14
	ESO	568.380	7
	GEMINI	580.543	8
	European Union	142.000	2
Other, insert rows	*Name of the institution*		
Contributions from the Sponsoring Entity			
	Name of the institution		

XII. APPENDICES

Information on output such as thesis, publications, books, congress abstracts, etc. remember to load it in the tables provided by the Program.
One of the staff members will contact you about it, providing you with a virtual address and a password to access the consolidated information that the Program has.
Please, include here any other appendices that you consider useful for this report providing an index with their titles.
Send to the Program all material available regarding **Outreach and Dissemination that you have not previously sent**.