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ASTRONOMY

RESEARCH PROJECTS

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ASTRONOMY RESEARCH IN THE STATE OF SÃO PAULO, BRAZIL

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Astronomy and astrophysics are fields of research that allow humanity to learn about some of the most fundamental questions that have ever been asked. Presently some of them would be: how did the universe begin? How did it evolve? What governs its expansion? What are the mechanisms that light a star and then cause it to die down? Are there other planets viable for life as we know it? What is Dark Matter and Dark Energy? How do Black-Holes form?

In the state of Sao Paulo there is a vibrant scientific community dedicated to these matters, involved in a diversified set of optical and radio astronomy projects, ranging from small group initiatives to the participation on the largest and most challenging international projects. Besides Astronomy itself, the research includes important branches to high energy physics, data science, instrumentation, engineering and innovation in companies, to name but a few. This research is strongly supported by the Sao Paulo Research Foundation (FAPESP); 53% of the scientific publications in Astronomy and Astrophysics with authors in Brazil have authors working in the state of São Paulo.

Astronomers frequently work in collaborations with colleagues from several countries, and organize initiatives to develop, build, and share the use of large observational instruments. Below we list initiatives that allow scientists in the state of São Paulo to participate in some of the most important telescopes built in the world, starting with the design, building and operation of the Southern Observatory for Astrophysical Research (SOAR) in the late 90's. Some of the projects presently supported by FAPESP are:

a) The Javalambre Physics of the Accelerated Universe Astrophysical Survey (J-PAS);

b) The Cherenkov Telescope Array (CTA);

c) The European Southern Observatory (ESO);

d) The Long Latin American Millimetric Array (LLAMA);

e) The Giant Magellan Telescope (GMT);

f) The Baryon Acoustic Oscillations In Neutral Gas Observations (BINGO).

This brochure illustrates other research projects supported by FAPESP in Astronomy and Astrophysics.

Because the observational challenges are so strict, many times the projects require the development of new instruments and new technology. This creates an opportunity for companies in the State of São Paulo to get involved in advanced R&D to develop and offer services and products.

The SP Astronomy Network (SPANet), announced in 2017, aims to increase coordination among the scientists and projects. Such coordination should lead to more research visibility to the national and international scientific community, to the general public, in terms of diffusion and education, as well as to industrial opportunities for the benefit of society.

PLANETARY FORMATION AND DYNAMICS: FROM THE SOLAR SYSTEM TO EXOPLANETS

André Izidoro Ferreira da Costa
School of Natural Sciences and Engineering / São Paulo State University (UNESP)
FAPESP Process 2016/12686-2 | Term: Nov 2016 to Oct 2020

The goals of this project is to evaluate models of formation and evolution of the Solar System and exoplanetary systems. In the context of the Solar System, it is expected that the results from this project can bring a better understanding of how the terrestrial planets, giant planets, and the asteroid belt formed and evolved from a dynamical point of view. In the context of exoplanets, the results from this proposal will help to constraint and distinguish the dynamical processes that played the leading role for the formation of systems of close-in super-Earths, the known most common type of planets in the galaxy.

ANDRÉ IZIDORO FERREIRA DA COSTA

Faculdade de Engenharia de Guaratinguetá
Universidade Estadual Paulista (UNESP)
Av. Dr. Ariberto Pereira da Cunha, 333
CEP 12516-410 – Guaratinguetá, SP –Brasil

izidoro.costa@gmail.com

STELLAR POPULATIONS IN THE MILKY WAY: BULGE, HALO, DISK AND STAR FORMING REGIONS; INSTRUMENTATION FOR HIGH RESOLUTION SPECTROSCOPY

Beatriz Leonor Silveira Barbuy
Institute of Astronomy, Geophysics and Atmospheric Science / University of São Paulo (USP)
FAPESP Process 2014/18100-4 | Term: Feb 2016 to Jan 2020

Figure 1. Image of the bulge globular cluster HP1 near the Galactic center, observed in the VVV survey.

The main aim of this project is to study the stellar populations and structure of the Milky Way, in order to better understand its formation and evolution. The targets are stars of the Galactic Bulge, Halo and Disk. The bulge is studied in terms of the chemical composition of individual stars as well as kinematics and ages of field and globular cluster stars.

The interplay between the bar and the oldest globular clusters trapped in the bar is studied by deriving their proper motions and distances.

The final goal is to know if the metal-poor stars in the bulge are the oldest in the Galaxy, as this would confirm that the bulge formed first. The Galactic halo is studied through abundance analysis of the most metal-poor stars. A selection of new targets, in particular carbon-rich metal-poor stars, is also carried out based on large surveys. For both the halo and bulge, the abundance pattern of the metal-poor stars ([Fe/H]$\approx$-1.0 in the bulge, and [Fe/H]<-2.0 in the halo) give information on the nature of the first supernovae, that produced the chemical enrichment of the gas from which these stars formed. The Galactic disk is studied through a) old super metal-rich stars that seem to have migrated from the inner parts of the Galaxy; b) metal-rich M dwarfs; c) young stars and star forming regions.

The group is expert in spectroscopy of cool stars, using model atmospheres to compute synthetic spectra, that are compared with the observed ones.

In the study of star clusters, we also use imaging in optical and near-infrared colours, to produce colour-magnitude diagrams, and deduce their ages. For star forming regions, X-ray data from the satellites XMM-Newton and Chandra have been obtained, in order to identify young stars.

Instrumentation is an important part of this project, with mainly the development of the CUBES spectrograph for the VLT/ESO, the ECHARPE spectrograph for the OPD/LNA/MCTI, and the MOSAIC multi-object spectrograph for the E-ELT. The MOSAIC spectrograph involves brazilian expertise on optical fibers.

Results on the Galactic Bulge include the abundance analysis of the bulge globular cluster HP 1, and the writing of an important review article on the Galactic bulge by B. Barbuy et al. We are also involved in the survey of the bulge region with VVV (Vista Variables in the Via Lactea), see Fig. 1 – Image of HP 1. In another collaboration the work by Bensby et al. including J. Melendez, analyses 90 microlensed bulge dwarfs. The analysis of data from the Hubble Space Telescope of NGC 6522 by L. Kerber et al. confirms that this is among the oldest clusters in the Galaxy, see Fig. 2 – Colour-magnitude diagram of NGC 6522.

Results on the Galactic Halo include the work published in Nature astronomy on a first age map based on blue horizontal branch stars, as part of the PhD thesis by R. Santucci under supervision by S. Rossi. The oldest stars are found out to 10-15 kpc from the center Precision abundances of metal-poor stars by Reggiani, Melendez et al. Results on young stars in the Galactic disk uses X-ray data from the XMM-Newton satellite, having identified stars in molecular clouds CMA R1 and nebula Sh2-296. Instrumentation work has progressed: Prototyping of the grating for CUBES is being concluded. The MOSAIC spectrograph entered Phase A of studies.

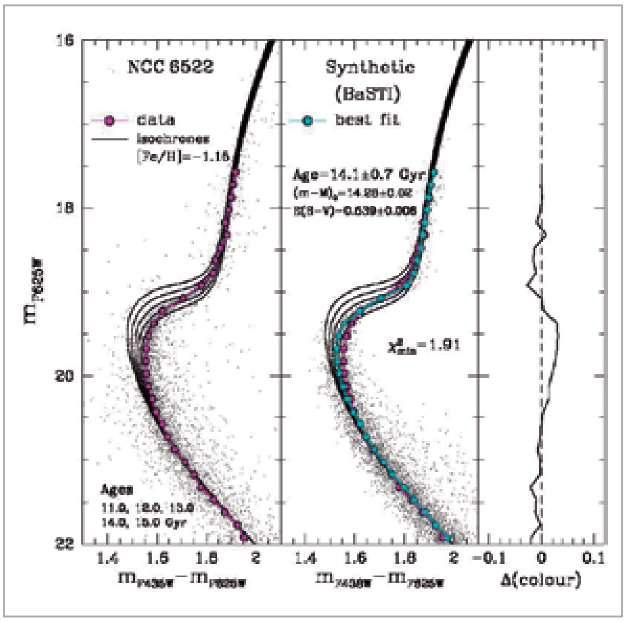


Figure 2. Colour-Magnitude Diagram of NGC 6522 observed with the Hubble Space Telescope, and proper motion cleaned. The theoretical isochrones overplotted indicate an age of 14 Gyr, close to the age of the Universe.

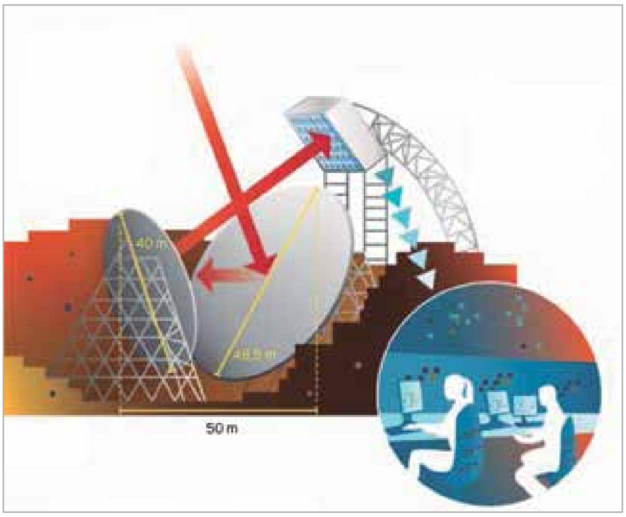
BEATRIZ LEONOR SILVEIRA BARBUY

Instituto de Astronomia, Geofísica e Ciências Atmosféricas
Universidade de São Paulo (USP)
Departamento de Astronomia
Rua do Matão, 1226
CEP 05508-900 – São Paulo, SP – Brasil

+55-11-3091-2810
b.barbuy@iag.usp.br

THE BINGO TELESCOPE: A NEW 21 CM WINDOW FOR EXPLORING THE DARK UNIVERSE AND OTHER ASTROPHYSICS

Elcio Abdalla
Physics Institute / University of São Paulo (USP)
FAPESP Process 2014/07885-0 | Term: Dec 2016 to Nov 2021



Source: BINGO

BINGO is a unique radio telescope designed to make the first detection of Baryon Acoustic Oscillations (BAO) at radio frequencies. This will be achieved by measuring the distribution of neutral hydrogen gas at cosmological distances using a technique called Intensity Mapping. Along with the Cosmic Microwave Background anisotropies, the scale of BAO is one of the most powerful probes of cosmological parameters, including dark energy. It will operate in the frequency range going from 0.96 GHz to 1.26 GHz, be of a two mirror compact range design with a 40 m diameter primary and have no moving parts. Such a design will give the excellent polarization performance and very low sidelobe levels required for intensity mapping. With a feedhorn array of 50 receivers, it will map a 15° declination strip as the sky drifts past the telescope. The partners in BINGO are Brazil, United Kingdom, Switzerland and Uruguay. The experience and science goals are also advantageous for any future involvement of Brazilian scientists in the Square Kilometre Array (SKA) project.

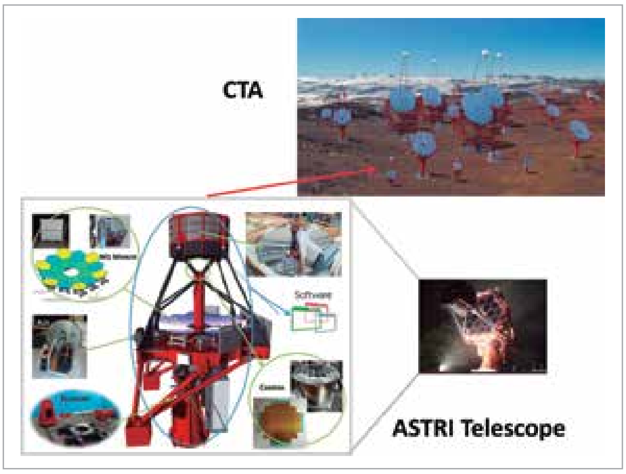
ELCIO ABDALLA

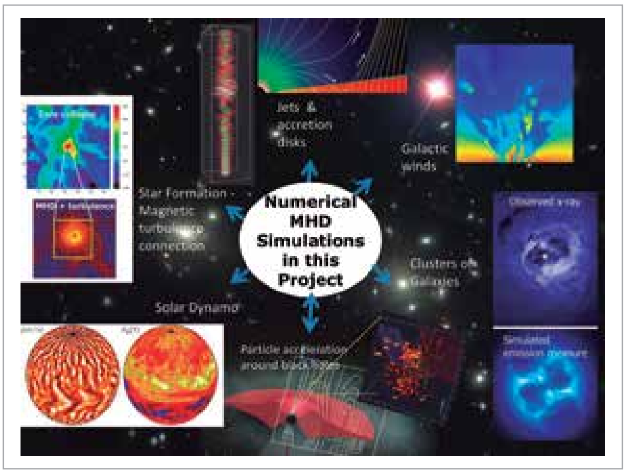
Instituto de Física
Universidade de São Paulo (USP)
Departamento de Física e Matemática
Rua do Matão, 1371
CEP 05508-090 – São Paulo, SP – Brasil

+55-11-3091-7036
eabdalla@if.usp.br

INVESTIGATION OF HIGH ENERGY AND PLASMA ASTROPHYSICS PHENOMENA: THEORY, NUMERICAL SIMULATIONS, OBSERVATIONS, AND INSTRUMENT DEVELOPMENT FOR THE CHERENKOV TELESCOPE ARRAY (CTA)

Elisabete Maria de Gouveia Dal Pino
Institute of Astronomy, Geophysics and Atmospheric Science / University of São Paulo (USP)
FAPESP Process 2013/10559-5 | Term: Aug 2014 to Jul 2018





Most of the visible matter in the Universe is in a plasma state, or more specifically is composed of ionized or partially ionized gas permeated by magnetic fields.

The goals of this Thematic Project are two-fold:

• The investigation of plasmas and high energy phenomena in Astrophysical systems by means of multi-dimensional magneto-hydrodynamical (MHD) studies employing high performance computing (HPC) and sophisticated codes. The studies include: astrophysical jets; black holes; acceleration and propagation of cosmic rays; galactic and stellar winds; role of turbulence and magnetic fields in star formation; solar and stellar dynamos; turbulent intra-cluster medium of galaxies and the origin of cosmic magnetic fields; and gamma ray astrophysics.

• The construction of the ASTRI – a Mini-Array of 9 Cherenkov telescopes – in partnership with Italy and South Africa. The MINI-ARRAY will be the (Cherenkov Telescope Array) CTA PRECURSOR. The CTA, is an international collaboration aiming at the construction of the largest gamma ray observatory – an array of ~100 Cherenkov telescopes – which will provide the deepest insight of the non-thermal high-energy Universe ever reached, with significant contributions to cosmology, astrophysics, astroparticle physics, and physics beyond the standard model. ASTRI is planned to be deployed by 2018, around which the big array will grow later.

Currently, the following main results have been achieved:

• Performance of numerical/theoretical studies of cosmic ray acceleration and production of gamma-ray radiation around black holes and relativistic jets with pioneerinig results on particle acceleration by magnetic reconnection, a process that can extract magnetic energy from the plasma of the system very efficiently and lead to stochastic particle acceleration and non-thermal high energy radiation.

• Performance of three-dimensional magneto-hydrodynamical simulations of the evolution of relativistic jets; galactic winds; turbulent intra-cluster medium of galaxies; and solar dynamo.

• The ASTRI telescope prototype testing is almost concluded and Brazilian engineers of this Thematic Project have participated in its development, and in particular, of the silicon photomultiplier camera (see figure).

ELISABETE MARIA DE GOUVEIA DAL PINO

Instituto de Astronomia, Geofísica e Ciências Atmosféricas
Universidade de São Paulo (USP)
Departamento de Astronomia
Rua do Matão, 1226
CEP 05508-900 – São Paulo, SP – Brasil

+55-11-3091-2826
dalpino@iag.usp.br

LLAMA : A BRAZILIAN-ARGENTINEAN RADIOTELESCOPE IN THE ANDES

Jacques Raymond Daniel Lepine
Institute of Astronomy, Geophysics and Atmospheric Science / University of São Paulo (USP)
FAPESP Process 2011/51676-9 | Term: Dec 2013 to Nov 2017

Figure 1. LLAMA Band 5 receiver cartridge receptor, which is now being tested in Groningen

Source: http://www.iar.unlp.edu.ar/llama-web/pictures.htm

A 12 m diameter radiotelescope for mm/sub-mm waves will be installed at a site at 4800 m altitude in Argentina, to perform research in different areas, like Astrochemistry, Solar Physics, studies of extragalactic jets from black-holes, star formation and VLBI (Very Long Baseline Interferometry), among others. The antenna will be installed at 20 km from San Antonio de los Cobres, Salta province, at about 150 km from the ALMA interferometer. The VLBI experiments will be done with nearby other radiotelescopes like ALMA, ASTE and APEX, and also with very distatn ones.

The antenna has been constructed and will be shipped to the telescope site. The road to reach the high altitude site has been openned and is being consolidated. A cryostat has been contructed in Japan with room for 3 cartrige-like receivers. Two cartriges receivers (band 9 and band 5, ALMA definition) have been mounted inside it, and firsts tests have been successful. The tests are being carried at Groningen, Holland. The whole set of drawings of the optical-like system of mirrors to bring the energy to the receivers have been concluded, and first steps of mechanical contruction of the "optical" system are being made.

JACQUES RAYMOND DANIEL LEPINE

Instituto de Astronomia, Geofísica e Ciências Atmosféricas
Universidade de São Paulo (USP)
Departamento de Astronomia
Rua do Matão, 1226
CEP 05508-900 – São Paulo, SP – Brasil

+55-11-3091-2757
jacques.lepine@iag.usp.br

EXPLORING THE UNIVERSE, FROM GALAXY FORMATION TO EARTH-LIKE PLANETS, WITH THE GIANT MAGELLAN TELESCOPE

João Evangelista Steiner
Institute of Astronomy, Geophysics and Atmospheric Science / University of São Paulo (USP)
FAPESP Process 2011/51680-6 | Term: Dec 2014 to Nov 2024

Large telescopes are necessary to study objects of low surface brightness and large distances as well as of high spatial and spectral resolution. As our understanding of the Universe advances, we realize that essential facts are not accessible even with our largest telescopes. Among the scientific goals of the GMT project, we can mention:

- Characterize habitable exoplanets. Such systems have low mass – this requires high spatial resolution, high signal/noise and very high stability. Spectral signatures of water and free oxygen are of fundamental importance.
- Solve the enigma of dark energy and dark matter, are among the most important and demanding scientific mysteries of current times.
- Observe light of the first stars and galaxy formation
- Study galaxy assembly since the Big Bang.
- Study how massive black hole formed and evolved and how they co-evolve with galaxies.
- Study how stars and planets are formed.
- Discover and study hundreds of objects in the Kuiper Belt.

1 – Mirror casting, figuring and polishing

In a telescope construction, casting and polishing the mirror is always in the critical path. When in full operation, the GMT will have 7 mirrors (one additional for coating). Each of them will have 8.4 m in diameter. Polishing the off-axis mirrors to specified shape was initially the greatest challenge for the project. This goal has been achieved, with a figure of merit of 17 nanometers rms versus 19 specified for M1. Additional mirrors were casted: M2, M3 and M4 are in distinct figuring stages for final polishing.

All this effort has been done in the Richard F. Caris Mirror Lab of the University of Arizona.

2 – Mount procurement

On February 24, 2017, the GMTO has released a Request for Proposals (RFP) for the final (fabrication) design and construction of the telescope's main structure ('the telescope mount'). This is a major step that, together with the primary mirror will make the heart of the telescope. This process is planned to be made in three steps:

- Selection of two primary contractor candidates (3 months).
- Selection of the best cost/benefit design (6 months).
- Final contract for fabrication.

3 – Project leadership

The leadership of the GMT has been changed in the last year. The current Chair of the Board of directors is Dr. Walter Massey (University of Chicago). Among many important positions, Dr. Massey was President of the National Science Foundation – NSF.

In February 2017 GMTO hired a new President: Dr. Robert Shelton. Among other positions, he was former president of the University of Arizona.

4 – GMT Brazil Office

In order to organize the activities of the GMT efforts in São Paulo, we organized the GMT Brazil Office. This office has the organogram bellow.

The goals of the GMTBr office are:

- Organize the GMT instrumentation activities

G-CLEF: This is the first light instrument and will focus high resolution and high stability spectroscopy; one of the main goals is to characterize habitable planets.

We are involved in developing an adaptive optics module for this instrument. The basic experiment is in operation in the optical laboratory at IAG/USP. Constructing the structure with composite materials is also in our plan.

GMACS: This is also one of the primary spectrographs for the GMT. We are organizing the system engineering team for this instrument. The optical design is also carried out by our team.

- A significant effort has been made in supporting and developing the instrumentation laboratories at IAG/USP. These laboratories will be inaugurated in March/2017.
- Coordinate the participation of São Paulo industries in the instrumentation and telescope construction. Many workshops and industry days have already been held in São Paulo and São José dos Campos with this purpose.

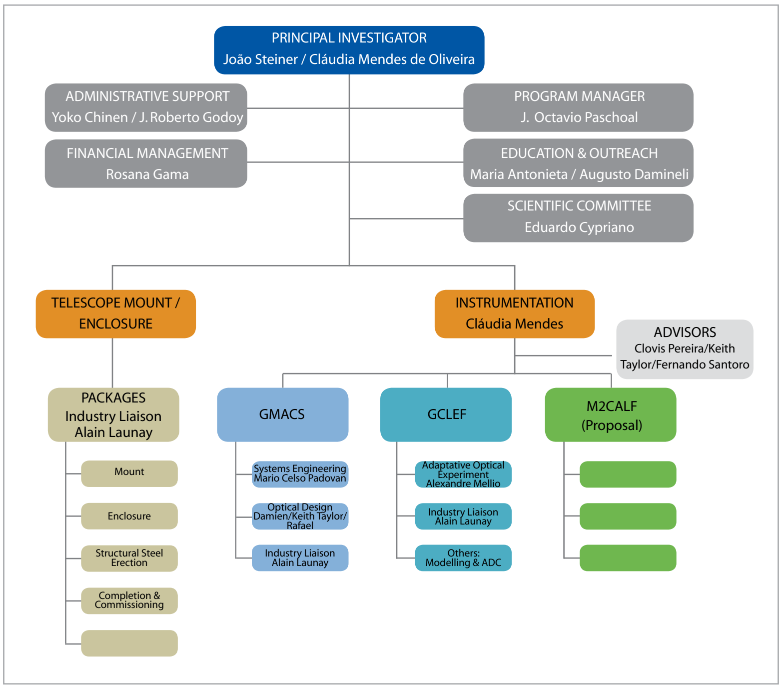


Figure 1. Organization chart of GMTBr Office

5 – Ground-breaking

On November 11, 2015 a ceremony was held in Cerro Las Campanas for the groundbreaking of the GMT telescope. The President of Chile Michelle Bachellet attended the ceremony as well as representatives of all partners.

6 – On-site development

The site was flattened for construction. Two towers for wind and seeing testing were erected. The initial facility construction started with a building for housing the on-site workers.

Figure 2. Site – Cerro Las Campanas, Chile

JOÃO EVANGELISTA STEINER

Instituto de Astronomia, Geofísica e Ciências Atmosféricas
Universidade de São Paulo (USP)
Departamento de Astronomia
Rua do Matão, 1226
CEP 05508-900 – São Paulo, SP – Brasil

+55-11-3091-2826
joao.steiner@iag.usp.br

HIGH PRECISION SPECTROSCOPY: IMPACT IN THE STUDY OF PLANETS, STARS, THE GALAXY AND COSMOLOGY

Jorge Luis Melendez Moreno
Institute of Astronomy, Geophysics and Atmospheric Science / University of São Paulo (USP)
FAPESP Process 2012/24392-2 | Term: May 2013 to Apr 2018

The project intends to perform precision spectroscopy of stars, aiming to study at unprecedented detail planet formation, stellar evolution processes, Galactic chemical evolution and primordial Big Bang nucleosynthesis. By applying a differential analysis technique, we can achieve a precision of about 0.01 dex in chemical composition, which is much better than typical errors (0.05 – 0.1 dex) found in previous works. As part of our project, we are searching for planets at high precision in radial velocity (1 m/s). The synergy of high precision radial velocities and high precision chemical abundances permits a detailed study of the connection between stars and planets. Our high precision work is mainly based on data obtained at the European Southern Observatory (ESO), especially through a large (100 nights) program to search for planets around solar twins.

We have been able to disentangle the chemical signature of planets from the chemical evolution of the Galaxy. Important results have been also obtained regarding nucleosynthesis in stellar interiors, as probed by the lithium and beryllium abundances of solar twins covering a wide range of ages. Precision spectroscopy of metal-poor stars have allowed us to obtain stringent constraints on chemical evolution models. Our Large HARPS/ESO program have resulted already on six papers, including chemical abundance studies, the decay of stellar rotation and activity with increasing ages, and the discovery of new planets around solar twins. Outreach has been also an important component of the project; our most important results have been broadly highlighted by the national and international media. In particular, our discovery of a Jupiter twin around a solar twin was widely communicated to the public.

Artist's impression of a Jupiter twin planet orbiting the solar twin star HIP 11915. The planet was discovered by Bedell, Melendez, Bean et al. (2015) using the European Southern Observatory (ESO). This Jupiter twin planet has a mass similar to Jupiter and orbits at a similar distance from its star as Jupiter does from the Sun. The system is an excellent candidate to host a "Solar System 2.0".

JORGE LUIS MELENDEZ MORENO

Instituto de Astronomia, Geofísica e Ciências Atmosféricas
Universidade de São Paulo (USP)
Departamento de Astronomia
Rua do Matão, 1226
CEP 05508-900 – São Paulo, SP – Brasil

+55-11-3091-2800
jorge.melendez@iag.usp.br

THE 3-D UNIVERSE: ASTROPHYSICS WITH LARGE GALAXY SURVEYS

Laerte Sodré Júnior
Institute of Astronomy, Geophysics and Atmospheric Science / University of São Paulo (USP)
FAPESP Process 2012/00800-4 | Term: Jan 2013 to Dec 2017

The objective of this project is twofold: i) to consolidate our scientific work with galaxy surveys, by supporting our participation in the projects J-PAS and PFS/SuMIRe, and ii) to coordinate the fabrication of the optical fiber sub-system of the PFS/SuMIRe instrument, which will make, from the Subaru telescope, one of the most ambitious spectroscopic surveys of the next decade.

Large galaxy surveys, either spectroscopic or photometric, are the best strategy to understand one of the most profound mysteries of contemporary cosmology: the nature of dark energy, the dominant component of the Universe, responsible for the acceleration of its expansion. These surveys provide a 3-D map of the galaxy distribution, which canhen be used to do cosmology (and other sciences) through statistical studies of features imprinted in this distribution. Indeed, they are also powerful tools to study from asteroids in the Solar System to our own Galaxy, from galaxy evolution to the large-scale structures of the Universe.

We are currently participating in the design of two new surveys: the Javalambre Physics of the Accelerating Universe Astrophysical Survey (JPAS) and the Prime Focus Spectrograph for the Subaru Measurement of Images and Redshifts survey (PFS/SuMIRe). JPAS is photometric, whereas PFS/SuMIRe is spectroscopic. Their potential are enormous from both the scientific and technological point of view. We already have graduate students and post-docs developing projects which have these surveys in mind, as well as technicians and engineers developing instruments for these surveys, namely, the panoramic CCD camera of JPAS, and the optical fiber sub-system for PFS/SuMIRe, called FOCCOS.

From a scientific perspective, both surveys are complementary: J-PAS will produce unique science up to z ~ 1.3 and PFS/SuMIRe will focus on the cosmology of the more distant universe, as well as in galaxy evolution, and in stars of the Milky Way and Andromeda, to study how these galaxies formed and what is the structure of their dark matter halos.

The JPCam, the camera which was built for the J-PAS survey is now being commissioned at JAO and J-PAS is scheduled to begin in the second semester of 2017. The construction of the optical fiber subsystem of the PFS instrument is also well advanced, and the PFS/SuMIRe survey should start in 2019.

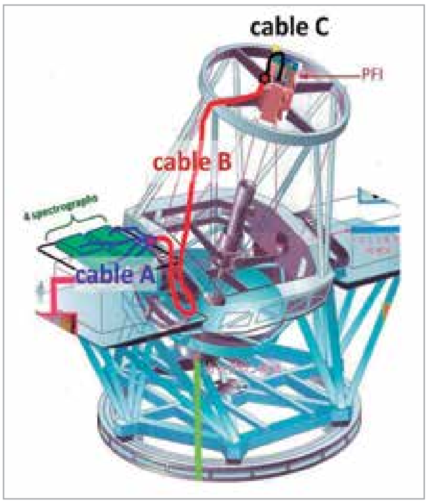


Figure 1. Illustration of the Fiber optics system in the Japanese telescope Subaru. (Source: LNA – Laboratório Nacional de Astrofísica)

Figure 2. JPCam, showing the CCDs mosaic. (Source: CEFCA – Centro de Estudios del Cosmos de Aragón)

LAERTE SODRÉ JUNIOR

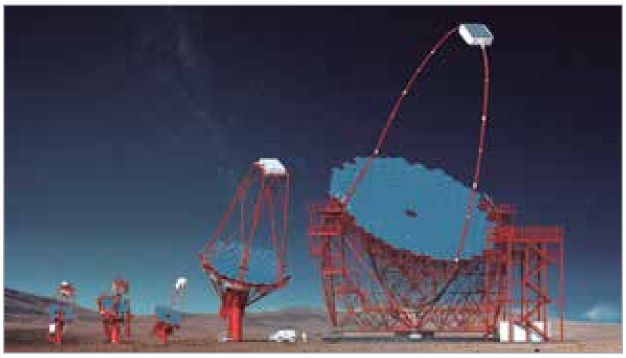
Instituto de Astronomia, Geofísica e Ciências Atmosféricas
Universidade de São Paulo (USP)
Departamento de Astronomia
Rua do Matão, 1226
CEP 05508-900 – São Paulo, SP – Brasil

+55-11-3091-2704
laerte.sodre@iag.usp.br

CHERENKOV TELESCOPE ARRAY

Luiz Vitor de Souza Filho
São Carlos Institute of Physics / University of São Paulo (USP)
FAPESP Process 2015/15897-1 | Term: Aug 2016 to Jul 2021

This project aims at assuring the permanence of the proponents in the world leadership in astroparticle physics through the participation in the Cherenkov Telescope Array Observatory (CTA). CTA is an international collaboration which intends to construct the new generation of ground gamma ray telescopes to study astroparticle physics among other subjects of astrophysical interest. The plan is to build hundreds of telescopes in three different configurations in order to detect gamma rays with energies between 10 GeV and 100 TeV. Ground-based gamma-ray telescopes have been proved to produce outstanding results over the last two decades. The CTA Observatory will have 10 times more sensitivity than any currently operating gamma ray telescope. In the past five years, the scientists involved in this project have developed astrophysical models, proposals for data analysis, simulations and instrumentation related to the physics and astrophysics of CTA. This effort was supported by FAPESP via two regular grants (process 2010/19514-6 and 2012/22540-4) and many scholarships. The success of the work done in the past years has culminated in this Thematic Project in which FAPESP is supporting us to improve our studies in: a) new physics: dark matter and Lorentz Invariance, b) cosmic rays and gamma rays: production and propagation, c) air showers and the configuration of telescopes, d) instrumentation of telescopes and e) astroparticle physics outreach.



Source: https://www.cta-observatory.org/project/technology

This project has already contributed to the development of fundamental science, innovation and formation of human resources. Since the beginning of our involvement with CTA, the group of scientist in this project have published several scientific papers in high impact factor journal. These publications are receiving numerous citations. Besides that, more than 10 students have been supported for graduate studies within this subject. The project includes the design, construction and test of a sophisticated metallic structure for the middle size telescope of CTA. The project was developed in collaboration with the Brazilian industry was tested under the conditions of the international CTA collaboration and approved to equip the middle size telescope. During the development of this structure, an innovative device to adjust the position of large weight load was developed and the process to request a patent is under way. These results were achieved before the CTA Observatory is taking data which increases our perspectives of success when the operation starts.

LUIZ VITOR DE SOUZA FILHO

Instituto de Física de São Carlos
Universidade de São Paulo (USP)
Departamento de Física e Informática
Av. Trabalhador Saocarlense, 400 – Caixa Postal 369
CEP 13560-970 – São Carlos, SP – Brasil

+55-16-3373-8727
vitor@ifsc.usp.br

SUPERDENSE MATTER IN THE UNIVERSE

Manuel Máximo B. Malheiro de Oliveira
Instituto Tecnológico de Aeronáutica (ITA)
FAPESP Process 2013/26258-4 | Term: Nov 2014 to Oct 2019

The exact conditions under which the fundamental degrees of freedom of strongly interacting matter, quarks and gluons, described by Quantum Chromodynamics (QCD), can be realized in Nature is still an open question. They certainly played a fundamental role in the very first instants of the Universe, being the quarks and gluons confined into hadrons when the temperature of the Universe dropped below 160 MeV. There are sites in the present-day Universe where the fundamental degrees of freedom of hadronic matter may still appear: the interior of super-dense stars, where the temperature can be as high as 10 bilion degrees Kelvin and the density overcomes the nuclear matter saturation density. A deeper and systematic study of systems containing compact stars may improve our understanding of the nuclear matter phase diagram. Nevertheless, giving the complexity of these stars, one can expect real advances only when applying various investigation approaches and tools, both theoretical and observational. In this research plan we propose an in-depth series of research lines aiming to increase our knowledge about compact stars and their interiors. Solid investments in space missions have been done in recent years, in particular the FERMI Gamma-ray Space Telescope, with the detection of several Gamma-ray pulsars, the ESA's INTEGRAL (INTErnational Gamma-Ray Astrophysics Laboratory) and XMM-Newton, together with CHANDRA and RXTE satellites that have revealed important astrophysical phenomena both in X- and Gamma-rays. Improvements in the understanding of the motion of matter around black holes and neutron stars are expected with the LOFT mission (Large Observatory For X-ray Timing). It will provide unprecedented information about strongly curved space-times and about matter under most extreme conditions. Facing these exciting prospects, new developments that can help explaining compact stars' phenomenology are needed. The proposal for this thematic project emerges in this scenario, joining researchers of six institutions of excellence of São Paulo State in the field of astrophysics of compact stars: ITA, IAG-USP, INPE, UFABC, UNIFESP and UFSCAR.

MANUEL MÁXIMO B. MALHEIRO DE OLIVEIRA

Instituto Tecnológico de Aeronáutica (ITA)
Praça Marechal Eduardo Gomes, 50
CEP 12228-900 – São José dos Campos, SP – Brasil

+55-12-3947-6884
manuelmalheiro@gmail.com

HIGH-ENERGY ASTROPHYSICS OF GALAXIES AND AGN IN THE COSMOLOGICAL CONTEXT BY CONNECTING NUMERICAL SIMULATIONS AND OBSERVATIONS WITH THE CTA AND ASTRI MINI-ARRAY

Paramita Barai
Institute of Astronomy, Geophysics and Atmospheric Science / University of São Paulo (USP)
FAPESP Process 2016/01355-5 | Term: Dec 2016 to Nov 2020

This project aims to explore high-energy astrophysical processes: star-formation, feedback from supernovae (SN) and active galactic nuclei (AGN) accretion, in the cosmological context. Using an approach going beyond the state-of-the-art, we will perform numerical magneto-hydrodynamical simulations and predict observables for next-generation observations. One main aim is to make predictions for the upcoming gamma-ray telescopes: Cherenkov Telescope Array (CTA), and its precursor – the ASTRI MINI-ARRAY. The scientific objectives are grouped into 4 broad topics.

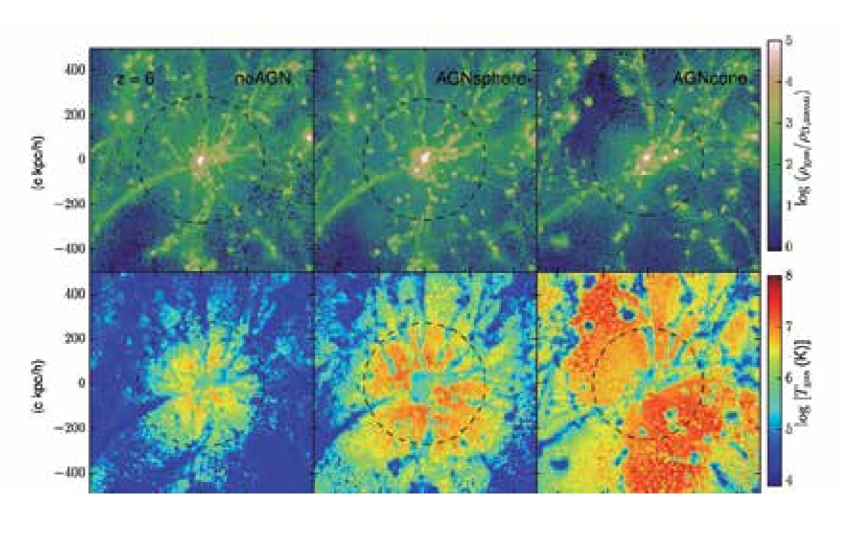


Figure 1. Source: http://adsabs.harvard.edu/abs/2016MNRAS.461.1548B (Barai et al. 2016. MNRAS, 461, 1548)

(1) Feedback from Star-Formation and SN Explosion in Galaxies: Magnetic fields produced in galaxies are dragged to the intergalactic medium by SN-driven galactic winds. We will study the history of gas outflows in different galaxies, and explore the origin of diffuse intergalactic magnetic fields (IGMFs); especially constrain the strength and the filling factor of the cosmic IGMFs.

(2) Central Black Hole Accretion, Outflows, and Jets from AGN: We will perform cosmological simulations, and compute the flux of high-energy diffuse emission coming from AGN, to set predicted constraints on the extragalactic background light, the production and propagation of very high-energy cosmic-rays and gamma-rays, that can be observed with the CTA.

(3) Dark Matter (DM) Annihilation Signatures From gamma-ray Detection: Efforts for detection of cold DM particles has so far been unsuccessful. We will:
- Explore the cross section threshold for DM self-annihilation.
- Consider two types of sources as the primary: (i) center of our Milky Way Galaxy, (ii) DM halos of nearby dwarf spheroidal galaxies.

(4) Support the science case development of CTA and ASTRI Mini-Array to Observe High-Energy Phenomena: Evaluate the performance of the MINI-ARRAY configuration and additional configurations consisting of medium-size-telescopes, to obtain the best array configuration.

The proposed investigation of high-energy astrophysical phenomena, by confronting numerical simulations with observations uniquely lies at the forefront of cutting-edge research in Astrophysics, bridges the gap between theory and observations, and expects high-impact results.

Many more energetic events would start to be detected in gamma-ray observations using the precursor ASTRI MINI-ARRAY and full CTA later, which has not been widely simulated; therefore it is important and timely to explore these phenomena, especially at earlier epochs. Currently this project is at a beginning phase. We have performed a dark-matter only simulation (using the SPH code GADGET-3) of a cubic cosmological volume of side 20 Mpc comoving, starting from redshift z=100 to z=0. We selected a massive halo from the box of total mass M_halo = 1e+12 Msun. We are currently preparing the zoom-in initial conditions to add baryons and perform hydrodynamical simulations. This will allow us to study simulated galaxies and their outflows. An example is shown in the *Figure 1* (showing gas density in the top row and gas temperature in the bottom row of 3 galaxies taken from 3 simulations) from a previous study (Barai et al. 2016) where AGN outflows were investigated.

PARAMITA BARAI

Instituto de Astronomia, Geofísica e Ciências Atmosféricas
Universidade de São Paulo (USP)
Departamento de Astronomia
Rua do Matão, 1226
CEP 05508-900 – São Paulo, SP – Brasil

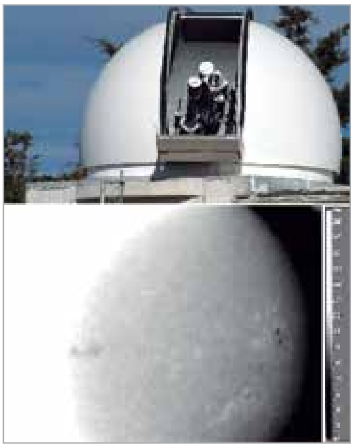
paramita.barai@sns.it

SOLAR FLARE DIAGNOSTIC IN AN UNPRECEDENTED FREQUENCY RANGE FROM MICROWAVES TO THZ FREQUENCIES: CHALLENGES FOR INTERPRETATION (FLAT)

Pierre Kaufmann
Mackenzie Presbyterian University
FAPESP Process 2013/24155-3 | Term: Dec 2014 to Nov 2019

Solar-T

Ground- and space-based observations of solar flares from radio wavelengths to gamma-rays have produced considerable insights but raised several unsolved controversies. The last unexplored wavelength frontier for solar flares is in the range of submillimeter and infrared wavelengths. Although the central focus of this proposal is on the description of solar activity at sub-THz and THz frequencies, it will be essential to analyze their relationships to observations at other radio, visible and higher UV, X and gamma-ray energy frequency ranges, attempting to find new clues to understand the processes of energy build up and explosive release in active regions. To attain these objectives we propose a special effort along the declining phase of the current Solar Cycle 24 (2014-2018), maintaining, upgrading ongoing programs and implementing new experimental activities. The proposal includes new research and developments on THz detecting sensors, filters, materials and integrated systems for the current applications. Special efforts will be given for the interpretation of results from solar flare THz emission, associated emissions at other wavelengths, in radio, visible, UV, X- and gamma-rays. Attention will be given to high energy physical processes occurring in solar flare particle acceleration and their comparison to mechanisms in laboratory scale accelerators.



Two main instrumental results were the installation of the 30 THz telescope in Argentina and the flight of the SOLAR-T (3 and 7 THz photometers) on a stratospheric balloon over Antartica.

An important instrumental achievement was the successful installation of the new 30 THz 20-cm telescope and new generation FLIR camera on the same mount of the HASTA (H-α Solar Telescope for Argentina) an instrument installe at the El Leoncito "Carlos Cesco" site. The new 30 THz microbolometer camera FLIR model A645sc 25, exhibited detectability of 50 mK which is 5 times more sensitive than the previously used camera FLIR AM20 (detectability of about 100 mK). The 20 cm short focus telescope replaces the previously used 15 cm telescope. The net gain was improved by a factor close to 10. The optical arrangement allows the observation of the full Sun simultaneously with HASTA high quality and high cadence H-α HASTA observations, both installed on the same polar mount. The "first light" was successfully obtained on August 17, 2016.

Considerable efforts were dedicated the SOLAR-T mission (double 3 and 7 THz photometers) flown on a stratospheric balloon over Antarctica together with GRIPS experiment University of California, Berkeley; Space Science Laboratory (SSL). The mission was accomplished successfully. A system of two photometers was built to observe the Sun at 3 and 7 THz named SOLAR-T. One innovative optical setup allows observations of the full solar disk can detect small bursts with sub-second time resolution over a field of view larger than the Sun's diameter. The photometers use two Golay cell detectors at the focal planes of 7.6 cm Cassegrain telescopes. SOLAR-T has been flown coupled to U.C. Berkeley solar hard X-ray and gamma-ray imaging spectro-polarimeter GRIPS experiment launched on a NASA CSBF stratospheric balloon from U.S. McMurdo base on January 19, 2016, on a trans-Antarctic flight ended on January 30. The SOLAR-T performed perfectly, thus becoming space qualified. Solar disk brightness temperatures were determined, 5200K at 3 THz and 5300K at 7 THz and flares were also detected.

PIERRE KAUFMANN

Universidade Presbiteriana Mackenzie
Rua da Consolação, 930 - Consolação
CEP 01302-907 – São Paulo, SP – Brasil

+55-11-2114-8000
kaufmann@craam.mackenzie.br

ADRIANA VALIO

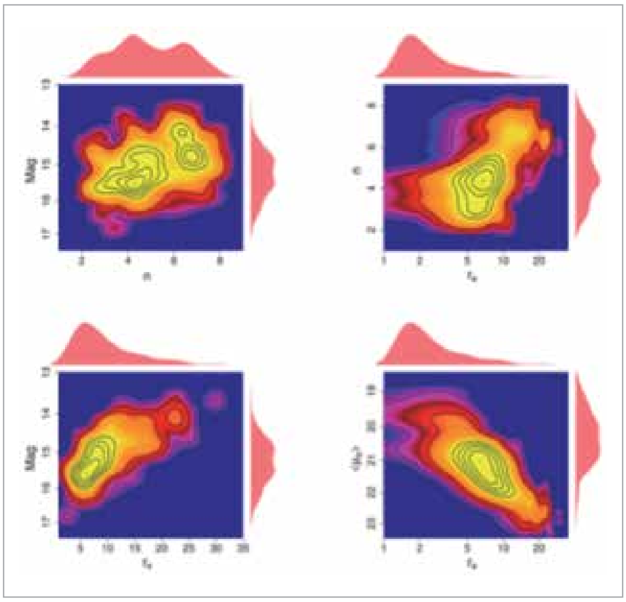
Pesquisadora Associada
adrivalio@gmail.com

WHAT DRIVES THE STELLAR MASS GROWTH OF EARLY-TYPE GALAXIES? BORN OR MADE: THE SAGA CONTINUES...

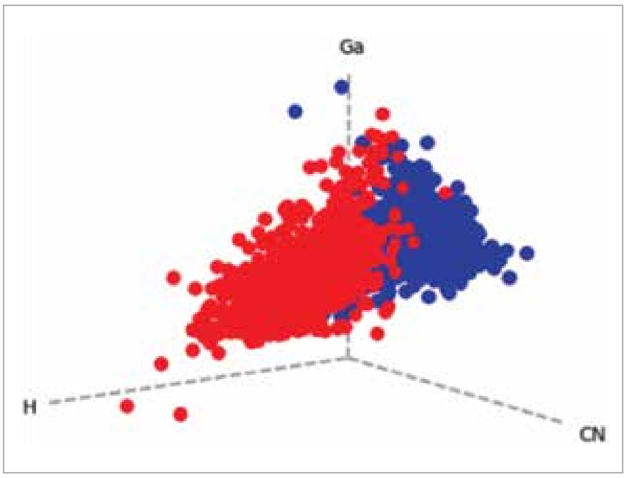
Reinaldo Ramos de Carvalho
National Institute for Space Research (INPE)
FAPESP Process 2014/11156-4 | Term: Aug 2015 to Jul 2018

Apart from the fact that studying the way galaxies evolve through cosmic time is complex in nature, some of the challenges of this project are related to two primary aspects. One is the development of the GPU version of BIE, which will enable GALPHAT to run two or three orders of magnitude faster. Beyond this specific application, BIE is a full set of libraries for performing Bayesian inference and may be extremely useful for other analyses done during this project and others as well. We will make BIE available on different platforms, so that its usage can be enlarged to all segments of our community. The second and maybe more important aspect of this project is to investigate the reality of the IMF variation with galaxy mass, a very controversial subject in current literature. The importance of this finding is directly linked to the fact that the implications are enormous. By studying the ETG properties in different environments and especially focusing on the star formation history in these systems we expect to unravel the intricate process of generating an IMF. The simulations we are planing to do together with the specific study of the stellar population models promise to be very effective tools to gain understanding of the physics behind the IMF.

MORPHOMETRY



GALPHAT



Our project aims to study how ETGs form and evolve through the investigation of their photometric and spectroscopic properties and environmental dependences. Among the expected fundamental results are: 1) the translation of the BIE package to a GPU architecture, which will be of paramount importance not only to our immediate goal (having GALPHAT running on a GPU cluster) but also to other astrophysical analyses where a Bayesian scheme may be needed; 2) Developing MORFOMETRYKA and GALPHAT for GPUs will allow us to have an unbiased statistical analysis of a large sample of ETGS. The Bayesian approach applied to images in the optical and infrared promises to be essential to study galaxy properties and how they depend on the environment where they reside. Three main results can be listed at this point of the project: 1) a working version of GALPHAT fully automatic described in Stalder et al. (2017, AJ, submitted); 2) A package for morphological analysis of galaxy images, described in the paper Sauter et al. (2017, submitted to AJ); and the development of a framework where environment is characterized by the velocity distribution of galaxies in a cluster, presented de Carvalho et al. (2017, submitted to AJ).

REINALDO RAMOS DE CARVALHO

Instituto Nacional de Pesquisas Espaciais (INPE)
Divisão Astrofísica
Av. dos Astronautas, 1.758
CEP 12227-010 – São José dos Campos, SP – Brasil

+55-12-3945-7210
rrdecarvalho2008@gmail.com

MOSAIC: THE MULTI-OBJECT SPECTROGRAPH FOR THE ESO EXTREMELY LARGE TELESCOPE (FAPESP-NOW 2015)

Silvia Cristina Fernandes Rossi
Institute of Astronomy, Geophysics and Atmospheric Science / University of São Paulo (USP)
FAPESP Process 2015/50374-0 | Term: Apr 2016 to Mar 2021

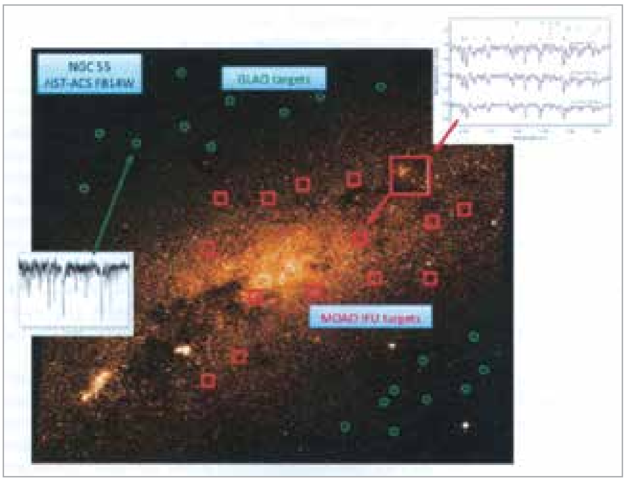


Figure 1. Hubble Space Telescope observation of the spiral galaxy NGC55 at a distance of 2 Mpc just beyond the Local Group [5]. We now have very limited access to the stellar populations of galaxies in the Local Group and beyond. With the E-ELT it will become possible to resolve individual stars in dense stellar populations and obtain spectra with MOSAIC's integral-field units supported by multi-object adaptive optics (MOAO); see red inset for a magnification of the resolved IFU field and corresponding simulated spectra. At the same time, MOSAIC fibers target several hundred point-like objects in the less densely populated field of NGC 55 (green circles, ground-layer adaptive optics). MOSAIC will also study the remnants of the very first population of stars, which are extremely metal poor and remain poorly understood.

With its 39m primary mirror, the ESO Extremely Large Telescope (E-ELT) will be the largest optical/near-infrared telescope ever built. MOSAIC (Multi-Object Spectrograph for Astrophysics, Inter-galactic medium studies and Cosmology) is expected to become the E-ELT´s workhorse instrument for astrophysics, intergalactic medium studies and cosmology in the coming decades. MOSAIC will fully explore the large aperture and superb spatial resolution of the biggest eye on the sky. Key science cases involve searching for extra-galactic planets, resolving stellar populations in thousands of nearby galaxies, and studying high-redshift galaxies at the edge of the visible universe.

MOSAIC is a fiber-fed spectrograph, covering the telescope´s full field of view with several hundred fibers and a dozen integral field units with adaptive optics capability delivering milli-arcsec spatial resolution, providing spectra ranging from the ultraviolet to the near infrared (380 – 2500 nm) at intermediate spectral resolution. The MOSAIC consortium includes scientists from Brazil, France, The Netherlands, and the United Kingdom, as main partners. Another 6 European countries are associated with the consortium at different levels. The Netherlands will be involved in designing and building the MOSAIC spectrographs; Brazil will contribute to its fiber system and spectrograph slit assembly.

This proposal aims to study and develop the fibers to spectrograph interface by producing a prototype slit assemblies for MOSAIC, exchanging expertise between Brazilian and Dutch technicians and industry, and to scientifically explore state-of-art MOS observations to optimize the scientific and technical requirements for MOSAIC.

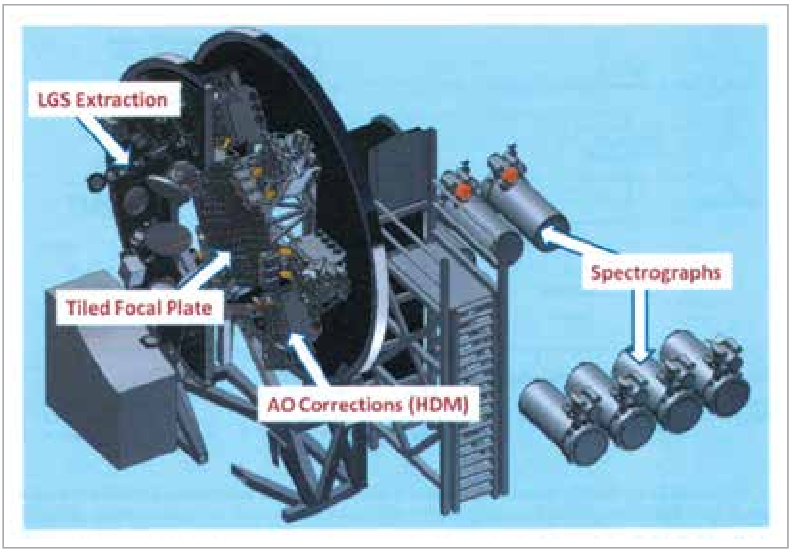


Figure 2. Overall MOSAIC instrument layout on the Nasmyth platform of the E-ELT. The Netherlands will contribute to the design and construction of the spectrographs, Brazil will be involved in the development of the fiber system and slit-unit assembly.

SILVIA CRISTINA FERNANDES ROSSI

Instituto de Astronomia, Geofísica e Ciências Atmosféricas
Universidade de São Paulo (USP)
Departamento de Astronomia
Rua do Matão, 1226
CEP 05508-900 – São Paulo, SP – Brasil

+55-11-3091-2822
rossi@astro.iag.usp.br

TOWARDS IMAGING THE EVENT HORIZON OF A BLACK HOLE (FAPESP_NWO)

Zulema Abraham
Institute of Astronomy, Geophysics and Atmospheric Science / University of São Paulo (USP)
FAPESP Process 2015/50360-9 | Term: Apr 2016 to Mar 2018

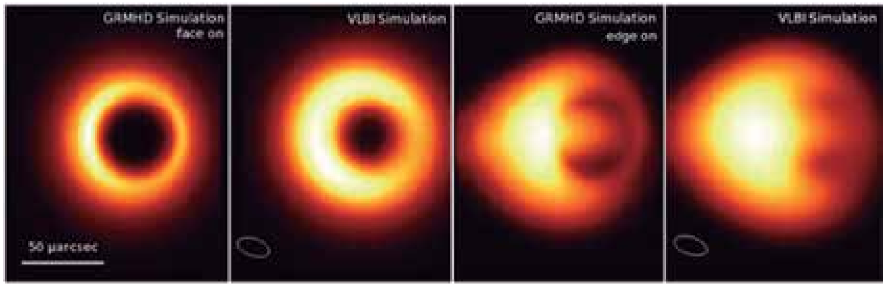


Figure 1. Simulation of the emission of an accretion flow around the BH in the Galactic Center. This is compared to a reconstructed image from simulated VLBI (Falcke et al. 2011, Mościbrodzka et al. 2009) for face-on and edge-on orientations.

One of the prime objectives of the Large Latin American Millimeter Array (LLAMA) is (sub)mm Very Long Baseline Interferometry (mm-VLBI) as the first one in a series of antennas that would make up the first interferometry VLBI network in Latin America. VLBI above 200 GHz (< 1.5 λmm) is a largely unexplored spectral domain and LLAMA, when operating with ALMA, will increase the angular resolution by ~10x compared to ALMA alone.

A global mm-VLBI network will achieve the highest possible high angular resolution available in all of astronomy. Such array will allow us to address one of the most fundamental predictions of General Relativity: the existence of Black Holes (BHs). Their defining feature is the event horizon, the surface that even light cannot escape. However, while there are many convincing BH candidates in the universe, there is still no conclusive proof for the event horizon. So, does general relativity really hold in its most extreme limit and is there an event horizon? To answer such questions we aim to obtain the first direct images of BHs on event horizon scales using VLBI: Sgr A*, the super-massive BH in the center of our Milky Way, and its counterpart in the nearby galaxy M 87.

To conduct the experiment requires establishing the required global mm-VLBI network of radio telescopes operating above 200 GHz, which we refer to as the Event Horizon Telescope (EHT). BlackHoleCam is participating in the technical and operational implementation of the EHT. Detailed theoretical simulations show that a BH embedded in an optically thin emission region would lead to a sharp "shadow" cast by the event horizon which can be detected by the EHT. Preliminary non-imaging observations with the EHT have already successfully detected emission around Sgr A* on event horizon scales. The EHT is in the process of adding stations and sensitivity that will enable imaging observations within the next few years. The aim of our project is to operationally make LLAMA VLBI-ready and prepare for and conduct the first VLBI observations with ALMA, the EHT, and other (sub)mm telescopes.

ZULEMA ABRAHAM

Instituto de Astronomia, Geofísica e Ciências Atmosféricas
Universidade de São Paulo (USP)
Departamento de Astronomia
Rua do Matão, 1226
CEP 05508-900 – São Paulo, SP – Brasil

+55-11-3091-2715
zulema.abraham@iag.usp.br

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- Laboratory for adaptative optics for the GMT project

  Marcelo Augusto Leigui de Oliveira | FAPESP Process 2015/50373-3 | Term: Apr 2016 to Mar 2018

- Distribuição da matéria em aglomerados de galáxias: uma visão completa dos bárions nas maiores estruturas virializadas do universo

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