Department of Theoretical Physics

• Introduction... page 1
• Current and future activities... page 5

1. Introduction

The Department of Theoretical Physics at UAM (www.ft.uam.es) was founded around 1970 with an aim for excellence at an international level. The core of the present department was then formed by the groups of professors F. J. Ynduráin (Elementary Particles), L. Bel (Gravitation) y O. Bohigas (Nuclear Physics), integrated in the UAM Physics Department led by Nicolás Cabrera.

Unfortunately, the Physics Department subdivided into five different ones by the middle 70's, one of them being the department described here. Nevertheless, the activity during that period constituted the first attempt –after the civil war- to do physics in Spain at a competitive level, and was a exceptionally important experience.

One of the signs of identity of the Department of Theoretical Physics is that, while consolidating the founding groups (notwithstanding the return to France of professors Bel and Bohigas to their CNRS positions), it supported the creation of high quality subgroups, even if not always corresponding formally to the traditional domain of theoretical physics. A quest for excellence in the widest sense was the guideline, with openings towards other emergent scientific disciplines.

In this way an experimental high energy physics group was created, led by professor Fernando Barreiro, as well as an astrophysics group led by professors Rosa Domínguez and Ángeles Díaz, and a computational neuroscience group led by professor Néstor Parga, who came from Bariloche for such purpose. In addition, Professor José M. Sanchez Ron –at present a RAE academicien- started to dedicate the best of his efforts to the study of History and Philosophy of Science. The Department of Theoretical Physics is currently a centre for research and collaboration across a large variety of disciplines; this is one of its remarkable singularities together with its international nature, both in activities and academic staff composition.

The largest part of the department has always been the theoretical group working on elementary particle physics which, together with colleagues from CSIC, constituted an ``associated" unit in the 90's which, later on, became the Institute for Theoretical Physics IFT-UAM/CSIC (www.ift.uam.es) in 2004. This institute has been very successful, being now a reference center for CSIC. The strong link between the Department of Theoretical Physics and IFT allows researchers to benefit from both the human and material resources of UAM and CSIC.

Currently, the department is composed of 101 members, 26 of them are permanent members (professors and associates) and 4 are *Ramón y Cajal* researchers. The IFT adds another 12 researchers, members of CSIC, several additional *Ramón y Cajal* researchers and many students and postdocs. An exceptional characteristic of the ensemble is the presence of eight tenured females, out of which four are full professors ("catedráticas"), a world record for a single department.

It is remarkable that, in spite of the dramatic effort made by the department to develop activities that otherwise wouldn't have taken place in UAM, it never disregarded the quest for excellence, which has been steadily maintained at a high level. Some present **quality indicators** for the department and IFT follow:

* Several members are regularly plenary speakers in the main world conferences.
* Four members are editors of the leading international journals.
* An outstanding average of 3082 cites/researcher and h-index of Hirsch of 26.6 holds for the IFT, and about 5000 cites/researcher hold for the Department of Theoretical Physics (which includes experimentalists) with global h-index over 200 (www.slac.stanford.edu/spires/).
* A recent h-index ranking shows that, in "Physics of Particles and Fields" in Spain, 4 out of the first 8 positions correspond to IFT members (2 from CSIC and 2 from UAM and thus from the Department of Theoretical Physics, with one of the latter holding the absolute first position.) (indice-h.webcindario.com).
* The CSIC survey of research impact (2000-2006) places IFT first among the 22 physics institutes in Spain. Also, the IFT Strategic Plan 2010-2013 was evaluated by an international scientific panel, and classified first in the area of physics within CSIC, with maximun grades (5/5) both in activities and internationalization.
* Most publications are made in collaboration with researchers and groups abroad. The group participates in 4 EU research networks (ITN) as Spanish node and has strong links to many excellent centres abroad. It also participates in other leading scientific projects – i.e. currently in four projects *Consolider Ingenio 2010:* GTC, CPAN, PAU and SyeC.
*The scientific Staff of the ensemble Department of Theoretical Physics-IFT reflects the internationalization. E.g. from the last 6 permanent positions allocated, 4 went to foreigners. Also, only 25% of the postdocs are spaniards. There is a steady incorporation of excellent *Ramón y Cajal* researchers (and with eight foreigners out of twelve incorporated). Besides, virtually all visitors – which often include Nobel prize winners- are from abroad.
* There is large number of seminars (3 per week), journal clubs (2 per week), colloquia (1 per month), workshops and conferences (about 10 per year), which are alive forums of discussion and (international) scientific communication. Ocassionally, some of the large leading world conferences are organized (i.e. Strings07, DIS2009, etc.).
* Also remarkable is the international reputation of our master and doctorate programs. The department has or participates in four masters (Theoretical Physics –to which which the IFT substantially contributes, Astrophysics, Nuclear Physics and Neuroscience), which regularly appear in the first places of European and Spanish quality rankings. For instance, the german "Center for

Higher Education Development" has selected in 2007/2008 the UAM physics group as one of the 20 best for master education – among 215 institutions- with 41% of the survey students being master students of our department or IFT (http://www.excellenceranking.org/eusid/EUSID). A fraction of the courses in our master are imparted by top level researchers from abroad (including singularly nobel prize winner M. Veltman course in 2007, in the master on Theoretical Physics). Also, our doctoral students are very competitive in the free international market and often are offered postdoc contracts from top world institutions, right after completing their phD, and move to them. These include Harvard, Princeton, Oxford, Fermilab, Padova, Paris, Utrecht, Cambridge, Munich, London, Rome…

All those indicators kept improving in parallel to the general raise of science in the country. The leading position of the Department of Theoretical Physics and the IFT in Spain corresponds to a quality similar to most of the research centers of reference in Europe and USA. Note that, according to the Web of Science analysis, the relative impact of the Physics field in Spain compared to the world is +37% (the first place among all fields), and the UAM is the leading university in Spain in the impact of its research.

2. Current and future activities

The multidisciplinary nature of the department results in much scientific wealth, as it bolsters a close and increasing exchange and collaboration between researchers of different specialities: i.e. theoretical and experimental physicists, astrophysicists and particle physicists, astrophysicists and nuclear physicists.

At present the department is active in the following fields:

ELEMENTARY PARTICLES – THEORY

All members of the department working in this field are also members of the IFT and the successes of the institute are basically shared. This activity is developed by the professors of the Theoretical Physics Department E. Álvarez, J. García-Bellido, B. Gavela, A. González-Arroyo, M.J. Herrero, L. Ibáñez, C. López, C. Muñoz, M. Maltoni, C. Peña, S. Rigolin and A. Sabio, together with the members of CSIC A. Casas, A. Donini, J.L. Fernández-Barbón, M. García-Pérez, C. Gómez, K. Landsteiner, E. López, J. Moreno, T. Ortín, G. Sierra y A. Uranga.

• Elementary particles phenomenology - The origin of mass.

This research focuses on the understanding of the origin of the mass of all objects in the visible universe and also on the composition of the dark sectors (dark matter and dark energy). It constitutes the core phenomenological research in High Energy Physics done in the group. It has an enormous importance due to its connection with the LHC accelerator, which will shortly provide new data, and to its intense collaboration with the experiments in neutrino physics. The collaboration with the High Energy Experimental Physics group of the Department should be most fruitful. This theoretical activity of the IFT was rated by the international committee which evaluated the Strategic Plan 2010-2013(PE10-13) of CSIC institutes, achieving maximum grades: 5/5 both at CSIC and international levels.

• Fields and strings

This line focuses on theoretical aspects of research in particle physics and is of fundamental structural relevance to all other research lines. An added positive value is its connection with mathematical research topics, which can lead to increased collaboration with mathmatics researchers. The rating of the PE10-13 mentioned above is also for this line 5/5, both at CSIC and international level.

• Astroparticle Physics and Cosmology

This lines deals with the origin and composition of the Universe and spans research in Astroparticle Physics and Cosmology. Both fields are undergoing a tantalizing transformation as a consequnce of the many running experiments which provide precise results about the universe at its largerst scales. Data of deep impact are expected to be available very soon, such as those from the PLANCK satellite or from dark matter experiments e.g. XENON. The collaboration and coordination in this field between IFT members (with PE10-13 rating in this area of 5/5 inside CSIC y 4/5 at an international level) and the extremely active and consolidated Astrophysics group of the department is very positive.

HIGH ENERGY EXPERIMENTAL PHYSICS

This activity is led by professors C. Albajar, F. Barreiro, J. Fdez. de Trocóniz, C. Glasman, L. Labarga, J. del Peso and J. Terrón. The group is deeply involved in the CERN (Geneva) experiments, in particular in the ATLAS and CMS experimentes of the "Large Hadron Collider" (LHC). Furthermore, in the context of ATLAS, a level-2 GRID centre has been built and is located in our department. The experimental particle physics group is also involved in the ZEUS collaboration of DESY (Germany). Furthermore, L. Labarga has recently joined one of the leading experiments in the world in the field of neutrino physics, Superkamiokande (based in Kamioka, Japan).

• LHC: ATLAS y CMS

The LHC is a particle accelerator (or particle accelerator and collider) with a length of 27km, located at CERN, in the border between France and Switzerland near Geneva. After being accelerated to high energies, the particle beams are allowed to collide and the new resulting particles are "collected" and identified. It was designed to collide hadron beams, in particular protons with energy of 7 TeV. Its main goal is to explore the validity and limits of the Standard Model of particle physics and the breaking of its symmetries, through the discovery of the Higgs particle and its properties, and possibly other new particles. After a false start, the particle beams have been switched on again in October 2009, and the data to be obtained over the next decade may be essential to understand the origin of all mass in nature and to the putative discovery of new fundamental physics laws.

ATLAS is one of the two main detectors which will collect the results of particle collisions in the LHC. The departmental activity in ATLAS focuses on two aspects: first, the development and operation for a particle detector essential to the experiment -the liquid argon electromagnetic calorimeter, partially built in the UAM- and secondly the preparation of physics analysis such as those oriented to the detection of heavy Z's, decays of the Higgs particle into four leptons and studies of the top quark.

The department also participates in the CMS collaboration, which is the other key detector in the LHC. In this area, the department activities consist in the design and operation of the muon detection system (Drift Tube Track Finder of the muon "trigger"), as well as on data analysis and the identification of new laws of physics.

- **Neutrino: Superkamiokande (SK)**

SK is a neutrino "observatory" located in Japan. Its detection of solar and atmospherical neutrinos was a key factor in the discovery of neutrino mass. It also aims to detect the potential disintegration of protons and also the neutrinos coming from supernovas elsewhere in our galaxy. Buried in a mine under 1.000 m, the detector consists on 50.000 tons of pure water surrounded by photomultiplier tubes.

The recent incorporation of the department to the SK experiment has several objectives: a) the development of a technique to identify the diffuse cosmic neutrino radiation coming from past supernovae explosions; b) precise measurements of the mixing among lepton families; c) the search for dark matter signals.

GRID

In the same way that the data handling led CERN particle physicists to invent the WEB as a means of internal information sharing, which later became ***the*** planetary communication tool, the newborn GRID system will be its equivalent for handling and sharing large data basis and specially computing.

The GRID is a technology of distributed computing, which allows to share heterogeneous computing resources of Computing Centres located worldwide. The basis is a "middleware" system which allows the connection among these centres, even when they have different local systems or portocols. From the user point of view, this GRID is like a "giant computer", where he/she can send her/his programs and perform data analysis.

In the level-2 centre of the UAM group –coordinated by Prof. J. del Peso- millions of particle collisions have been already simulated and many future observation channels of LHC physics have been foreseen and quantified. When the LHC will be in regular operation, real data from ATLAS will be stored in the GRID and any experiment user will be able to carry through her/his analysis of those results. The capacity of this UAM facility is, for the year 2009, of about 160 TeraBytes for disk storage, equivalent to that of 400 3GHZ Pentium4 PCs. The UAM GRID group, in collaboration with Information Technologies at UAM, has also benefited from the computers in the computing classrooms, for carrying through scientific calculations after teaching hours. The use of the GRID will be multidisciplinary; in fact, other fields such as Nuclear Physics already use the local system.

NUCLEAR PHYSICS

This activity is led by Profs. L. Egido, A. Poves and L.M. Robledo. They perform theoretical research on nuclear structure, developing methods which represent the "state of the art" of the discipline worldwide. The future activity will explore collective nuclei motion (superdeformation, superfluidity, etc), the structure of exotic nuclei and weak interactions, and in particular *neutrinoless double beta decay*, which has a deep impact on neutrino physics and on the understanding of the fundamental physics laws.

This team also works on the theoretical description of fission at finite temperature, on odd nuclei as well as on neutron-rich nuclei, with potential applications to nuclear astrophysics. New effective interactions and calculational methods to solve many-body problems are also being developed at present. An example of the interdisciplinary communication of our department is the fact that one of our former *Ramón y Cajal* researchers in nuclear physics is nowadays a young international leader in nuclear astrophysics.

ASTROPHYSICS AND COSMOLOGY

The scientists working in astrophysics in the department include Profs. C. Eiroa, R. Domínguez Tenreiro, A. Díaz, G. Yepes, A. Knebe and E. Villaver. It is of mutual benefit for both the Department of Theoretical Physics and IFT the activities and expeditions towards cosmology and astroparticles developed by IFT members such as Prof. J. García-Bellido, C. Muñoz and others.

• Star formation and exoplanets

Star formation, planetary systems and planet are all links in the same chain: the gravitatory collapse of a fragment of a molecular cloud, which leads to star formation and then to circumstellar disks where the planets will be formed. There are several running projects regarding this evolutive chain: i) Protostars and young star objects; ii) Evolution of protoplanetary disks into planetary disks; iii) Kuiper belts and exozodiacal light in mature stars of the solar vicinity; iv) Detection and characterization of Earth-like planets in near stars.

This departamental research takes place in the framework of large international consortia (i.e. DUNES and GASPS related to the space telescope Herschel or ARENA).

• **Extragalactic astrophysics**

It has been understood that the chemical evolution of the different systems in the Universe provide key elements to identify the processes leading to galaxy formation. The subgroup of Extragalactic Astrophysics studies these processes, both from a theoretical -modelling- point of view and through observations, devising methodologies for the determination of chemical abundances in the interstellar gas and in star populations.

The team also studies the "activity" (high-energy radiation emission) in galaxy nuclei and its connection with violent star formation. This group is leader in the study of star formation in that type of environments.

• **Computational Astrophysics**

This subgroup develops simulations of visible structures in the Universe at different astronomical scales: from the largest – of order of billion light-years -, to the smallest, e.g. galaxies such as the Milky Way. The gravitational effects of the dark matter and dark energy components are taken into account and explored, as well as gas-dynamic effects. These simulations are a virtual laboratory which serves to test and verify theories and astrophysical and cosmological models; it is also a tool to design future observational and instrumental strategies.

The team participates in large international collaborations on Universe simulations (i.e. DEISA consortium, http://www.deisa.org), and some of them, as Mare Nostrum Universe, are still the biggest simulations in the world that simultaneously include gas and dark matter.

COMPUTATIONAL NEUROSCIENCE

This is an emergent field and a meeting point between exact sciences, e.g. physics and mathematics, and biomedicine and it studies the brain and cognitive functions. In the department, Prof. N. Parga leads the creation and future expansion of this group, which now explores the neuronal activity during different cortical states of activity: i) spontaneous activity of slow waves during a sleep phase, ii) under anaesthesia, iii) in the animal awake but inactive, iv) spontaneous activity (asynchrony) in the active animal. Another research line uses visual stimulations to explore the reception processes of the simple cells in the primary visual cortex.

In the future, a modelling project of spatial navigation is to be undertaken, using the existing experimental information about the hippocampus and the entorhinal cortex. It will be implemented in collaboration with other neuroscience laboratories and robotic teams, being its goal the implementation of the model in a brainmachine system.

QUANTUM INFORMATION AND FOUNDATIONS OF QUANTUM MECHANICS

Quantum computing is a computational paradigm qualitatively different from classical computing. It is based on the use of qubits instead of bits, providing new logical doors that allow to invent new more powerful algorithms. A given task can have substantially different complexity in classical computing and in quantum computing, which has led to enormous expectations because some previously unmanageable problems became manageable. Professor J. L. Sánchez Gómez works in this line together with researchers from other Spanish centres, including members of the Mathematics and Fundamental Physics Institute of CSIC. Also, G. Sierra, member of the IFT, works in quantum computing.

HISTORY OF SCIENCE

Prof. Sánchez Ron works at present in two areas of history of science: 1) History of Physics in XIX and XX centuries; 2) History of Science in Spain in both centuries. The first line currently focuses on i) quantum physics, in the period 1926 to 1950, aiming to complete the second volume of his "History of quantum physics", whose first volume covered the period 1860-1925; ii) Development of the Theory of Relativity and, in particular, the popularity of Einstein theories in Great Britain ("Einstein Studies" series, published by Birkhäuser). As for the second line, he currently works mainly on: i) extension/rewriting of the biography of Miguel Catalán ; ii) Santiago Ramón y Cajal mail; iii) Spain and CERN.

SUPERCOMPUTING

The description given above should convey that both the Department of Theoretical Physics and the IFT are leading centres in computing and informatics development. In addition to the level-2 GRID system and the collaboration in Mare Nostrum already mentioned, there are two Beowulf clusters on site working at full capacity.

INFRASTRUCTURES

It is relevant to mention the forthcoming opening of the IFT-ICMAT new common building, which will allow to receive a large number of visitors of those two UAM-CSIC centres, and will allow to bolster quality research activities. The building will have several seminar rooms and an auditorium; these facilities should allow to organize international conferences, and extended workshops. However, in order to take advantage of this opportunity, there is a need of additional support in management and computing.

Notice though that only the members of IFT (and ICMAT) will benefit directly from this new space in their daily work, at variance with the rest of the Department of Theoretical Physics, which currently suffers from a severe lack of space, beyond reasonable limits.