Theoretical Physics

The activities of the group include several different items that are developed below.

Nuclear structure and nuclear reactions in low energies

New developments in radioactive beam acceleration and large detector arrays have allowed, not only the study of new nuclear systems, but also a much better knowledge of some spectroscopic observables. Hence, there are new possibilities to develop and test many body techniques applying in some cases previously developed solutions to new systems.

- Since the nuclear stability line departs from N » Z for A > 40, previous detailed spectroscopic studies of those type of nuclei had been performed in lighter systems. This can be and is being studied using shell model techniques, either with large scale calculations or schematic models based in group theoretical classifications as well as within a collective description of the relevant degrees of freedom.
- Some phenomena related to octupole or tetrahedral degrees of freedom are more noticeable at the onset of quadrupole deformation regions. We are using our experience on these types of excitations to find a relation between the relative influence of the T=1 and T=0 channels of the nuclear interaction, the effects of octupole components in the deformed systems and the alpha-like correlations.
- It has been possible to study the thermal character of giant resonances built on top of nuclear excited states. From the experimental data of giant dipole resonances results an excess of low energy photons, which is at odds with the predictions of simple models.
- The existence of neutron skin in neutron reach nuclei has been studied in connection with the excitation of isovector dipole and quadrupole giant modes via isoscalar nuclear probes. In the case of large neutron excess, important contributions are obtained for the nuclear excitation and constructive interference is found between nuclear and Coulomb contributions.

Chaos and complex systems

- Quantum Maps
  Quantum maps provide the simplest, yet highly non-trivial, arena for the investigation of the quantum properties of chaotic systems. As simple models of Poincare sections of realistic Hamiltonians or of time dependent "kicked" systems, they provide a testing ground for semiclassical approximations, correlations, universalities, localization, etc. We have developed techniques for the construction, semiclassical behaviour and phase space description of the baker's map, the Smale horseshoe, cat maps, etc.
- Quantum Billiards
  Billiards in 2-D provide some of the best realistic models where wave and particle behaviour can be studied and related. Besides their intrinsic theoretical interest they describe the behaviour of ballistic electrons in mesoscopic cavities or of light in optical microcavities. The group has studied extensively the highly excited spectrum of plane chaotic billiards and its semiclassical description in terms of periodic orbits. A very efficient "scaling" method for the precise calculation of very excited eigenstates has been developed, which is now the best available. A theory of short periodic orbits is under active development with aim of taming the exponential increase in the number of periodic orbits needed for the semiclassical description of spectral properties.
- Quantum Algorithms
  Quantum algorithms of interest to quantum information can be viewed as unitary maps. Thus, we can apply semiclassical techniques, phase space analysis, and long time behaviour characteristics of quantum maps to the operation of quantum circuits, providing a novel approach in this area.
- Transport Phenomena in Mesoscopic Systems
  Application of the general methods of chaotic dynamics to the study of mesoscopic systems. We have studied persistent currents and the effects of surface roughness in ballistic cavities and the statistical properties of the fluctuations in the total energy in a non-interacting fermion system.
- Chaotic Scattering at the Nuclear Coulomb Barrier
  There are interesting and characteristic anomalies in the heavy ion cross sections and angular distributions at backwards angles that can be interpreted as arising from chaotic scattering due to the coupling of intrinsic and translational degrees of freedom at Coulomb barrier energies. We have modeled these processes and proposed experiments to test these characteristics.

Field theoretical methods in strongly interacting systems

- Several aspects of the strange baryon structure and interactions have been investigated within the framework of the SU(3) chiral topological soliton models. In particular, we have studied the amplitudes for non-leptonic weak decays, the nucleon-hyperon potentials and the one-loop corrections to the baryon masses. Using the same type of models we have also performed the analysis of the strange, charm and bottom multibaryon spectra for baryons numbers up to B=9. For this purpose, we have considered some ansätze for the chiral field based on rational maps.
- The properties of the skyrmions in 2+1 dimensions have been studied. Such systems are relevant to understand some features of the Quantum Hall Effect.
- Nuclear structure problems related to the description of the double beta decays have been investigated. Special attention was paid to the difficulties related to the treatment of the zero modes associated to the breaking of isospin symmetry. For this purpose a formalism based on the use of BRST symmetry was developed.
- Some properties of the QCD chiral phase transition at finite temperature and chemical potential using non-local extensions of the Nambu-Jona-Lasinio model. We have made predictions for the position of the tricritical point" (chiral limit) and the "end point".
- The problem of the center of mass in many-body nuclear systems has been revisited. Once the counter terms needed to satisfy translational invariance were determined, collective variables have been introduced. The problems associated with the overcompleteness and divergencies were solved using BRST invariance. The formalism has been applied to the calculation of some electroweak operators relevant to muon-electron conversion process.
- Another topic, which has been extensively studied, is that of nuclear microscopical models and approximations in connection to their use in predictions for observables in exotic electroweak processes such as double beta decay.
- Investigations concerning the edge states in the fractional Quantum Hall Effect. In particular, different predictions of the two classes of theories currently used to describe these states have been studied. We have also considered a Chern-Simons theory in 2+1 dim to describe the quasiparticles in the Pfaffian states.

Inhomogeneous quantum fluids

The investigation of the structure and stability of helium systems is the object of many theoretical and experimental works. Mainly two different theoretical approaches for investigating helium systems have been successfully employed in the literature:

- A self-consistent variational formalism based on the use of interatomic potentials within the framework of the theory of correlated basis functions in conjunction with the hypernetted chain expansion.
- A semiphenomenological approach which uses a density functional. In this semiphenomenological description the energy of the systems is written in terms of a functional depending of the density.

Among the properties of inhomogeneous superfluid ^{4}He, we have mainly studied the stability of helium films. This feature is determined by variational properties of the chemical potential m which is introduced in order to impose the conservation of the particle number *N* when solving the equation for the density profile, and by the requirement of a negative surface tension.

The behavior of films adsorbed onto solid planar substrates of alkali metals has been studied. The calculations were carried out by using the density functional formalism. Results indicate that only the surface of Cs is not wetted by ^{4}He at T=0 K. Planar substrates of lighter alkali metals (i.e., Rb, K, Na, and Li) are wetted by planar films of liquid ^{4}He at T=0 K.

Finally, we have also focused our attention on helium systems with cylindrical geometry. In this case a stability criterion consistent with basic equations of the thermodynamics was derived.

"Non-leptonic hyperon weak decays in the Skyrme model revisited"

D. Gomes Dumm, A.J. García and N.N. Scoccola

Phys. Rev. ***D62*** *(2000) 14001*

Non-leptonic hyperon weak decays are investigated in the SU(3) Skyrme model. We use a collective coordinate scheme, following the approach in which the symmetry breaking terms in the strong effective action are diagonalized exactly. To describe the weak interactions we use an octet dominated weak effective lagrangian that leads to a good description of the known 2π and 3π kaon decays. We show that the observed S-wave decays are reasonably well reproduced in the model. On the other hand, our calculated P-wave amplitudes do not agree with the empirical ones even though both pole and contact contributions to these amplitudes are properly taken into account. Finally, an estimate of the non-octet contributions to the decay amplitudes is presented.

"Structure of the vacuum states in the presence of isovector and isoscalar pairing correlations"

D.R. Bes, O. Civitarese, E.E. Maqueda and N.N. Scoccola

Phys. Rev. ***C61*** *(2000) 024315*

The long standing problem of proton-neutron pairing and, in particular, the limitations imposed on the solutions by the available symmetries, is revisited. We look for solutions with non-vanishing expectation values of the proton, the neutron and the isoscalar gaps. For an equal number of protons and neutrons we find two solutions where the absolute values of proton and neutrons gaps are equal but have the same or opposite sign. The behavior and structure of these solutions differ for spin saturated (single l-shell) and spin unsaturared systems (single j-shell). In the former case the BCS results are checked against an exact calculation.

"Multibaryons with heavy flavors in the Skyrme model"

C.L. Schat and N.N. Scoccola

Phys. Rev. ***D61*** *(2000) 034008*

We investigate the possible existence of multibaryons with heavy flavor quantum numbers using the bound state approach to the topological soliton model and the recently proposed approximation for multiskyrmion fields based on rational maps. We use an effective interaction lagrangian which consistently incorporates both chiral symmetry and the heavy quark symmetry including the corrections up to order 1/m_Q. The model predicts some narrow heavy flavored multibaryon states with baryon number four and seven.

"Multibaryons as symmetric multisyrmions"

J.P. Garrahan, M. Schvellinger and N.N. Scoccola

Phys. Rev. ***D61*** *(2000) 014001*

We study non-adiabatic corrections to multibaryon systems within the bound state approach to the SU(3) Skyrme model. We use approximate ansatze for the static background fields based on rational maps which have the same symmetries of the exact solutions. To determine the explicit form of the collective Hamiltonians and wave functions we only make use of these symmetries. Thus, the expressions obtained are also valid in the exact case. On the other hand, the inertia parameters and hyperfine splitting constants we calculate do depend on the detailed form of the ansatze and are, therefore, approximate. Using these values we compute the low lying spectra of multibaryons with B <= 9 and strangeness 0, -1 and -B. Finally, we show that the non-adiabatic corrections do not affect the stability of the tetralambda and heptalambda found in a previous work.

"Multibaryons in the Skyrme Model"

N.N. Scoccola

Hadron Physics 1999 - AIP Conference Proc. 508 (2000) 63

Low-lying multibaryon configurations are studied within the bound state approach to the SU(3) Skyrme model. We use approximate ansatze for the static background fields based on rational maps which have the same symmetries of the exact solutions. To determine the explicit form of the collective Hamiltonians and wave functions we only make use of these symmetries. Thus, the expressions obtained are also valid in the exact case. On the other hand, the meson bindings, inertia parameters and hyperfine splitting constants we calculate do depend on the detailed form of the ansatze and are, therefore, approximate. Using these values we compute the low-lying spectra of multibaryons with B<=9 and strangeness 0 and -B . With these results the stability of some multilambda configurations is discussed.

“Electromagnetic and Weak Decays of Hyperons in the Skyrme Model”

N.N. Scoccola

*Progress in Particle and Nuclear Physics **44** (2000) 243*

We report on the result of some investigations concerning the radiative decays of decuplet baryons and the non-leptonic weak decays of the octet baryons in the context of topological chiral soliton models. Our results are compared with those of alternative baryon models. For the radiative decays we find that the predictions are similar to those of quark models. In the case of the non-leptonic weak decays, we find that although the predicted S-wave amplitudes are in rather good agreement with the observed values, the model is not able to reproduce the empirical P-wave amplitudes. Thus, in contrast to previous expectations, the Skyrme model does not seem to provide a solution to the long-standing 'S-wave/P-wave puzzle'.

“Multibaryons in the collective coordinate approach to the SU(3) Skyrme model”

C.L. Schat and N.N. Scoccola

*Phys. Rev. **D62** (2000) 074010*

We obtain the rotational spectrum of strange multibaryon states by performing the SU(3) collective coordinate quantization of the static multi-Skyrmions. These background configurations are given in terms of rational maps, which are very good approximations and share the same symmetries as the exact solutions. Thus, the allowed quantum numbers in the spectra and the structure of the collective Hamiltonians we obtain are also valid in the exact case. We find that the predicted spectra are in overall agreement with those corresponding to the alternative bound state soliton model.

“Comparison of density-functional approaches and Monte Carlo simulations for free planar films of liquid ^{4}He”

L. Szybisz

*European Physical Journal **B14** (2000) 733*

Density functionals proposed in the literature for describing the behaviour of liquid helium at T=0 K are examined. In so doing, several properties of the ground states of free films of superfluid ^{4}He are calculated by using zero- and finite-range density functional theories and these results are compared to that computed with Monte Carlo simulations. We mainly focus the attention on the energy per particle of the slabs, the surface tension and the width of the liquid-vacuum interfaces, all as a function of the inverse of coverage. The largest differences are found in the case of the surface widths.

“Liquid-drop-like model for cylindrical helium systems”

L. Szybisz

*Physica **A283** (2000) 193*

Free liquid ^{4}He at T=0 K with cylindrical symmetry is studied. The ground-state energy and chemical potential are computed by using a density functional approach. A liquid-drop-like model is formulated for analyzing the behavior of these observables as a function of the size of the systems. It is shown that such a model allows to get precise information about the asymptotic values of the energy per particle and surface tension.

“Wetting of potassium surfaces by superfluid ^{4}He: A study using variational properties of the chemical potential”

L. Szybisz

*Phys. Rev. **B62** (2000) 3986*

The wetting of planar surfaces of K by superfluid ^{4}He films at T=0 K is theoretically studied. In order to examine the consistency of numerical results new variational properties of the chemical potential, $\mu$are derived. Two substrate-adsorbate interactions are analyzed: (a) the standard “3-9” one and (b) the more elaborated potential recently proposed by Chizmeshya, Cole, and Zaremba (CCZ). New results calculated within the framework of two different nonlocal density functionals (namely, those known as the Orsay-Paris and Orsay-Trento formalisms) are reported. It is demonstrated that, the numerical solutions obtained from the theoretical equations verify with high accuracy the derived variational conditions. The main output of this investigation is the finding that, for both analyzed adsorption potentials, thick enough helium films exhibit a positive square of the third-sound velocity. The wetting of a potassium substrate by superfluid ^{4}He at T=0 K suggested by experimental data is guaranteed in the case of the recent CCZ potential.

"Wetting of planar substrates of rubidium by liquid films of ^{4}He"

L. Szybisz

Phys. Rev. ***B62*** *(2000) 12381*

The wetting of planar solid surfaces of Rb by superfluid ^{4}He films at T=0~K is examined theoretically the calculations were carried out by (i) using the most elaborated nonlocal density functional known as the Orsay-Trento proposal and (ii) assuming that the helium atoms interact with the substrate via the potential recently worked out by Chizmeshya, Cole, and Zaremba. The asymptotic surface tension was evaluated by applying two different procedures. Our results indicate that films of ^{4}He wet Rb at zero absolute temperature.

"Quantization of multidimensional cat maps"

A.M.F. Rivas, M. Saraceno and A.M. Ozorio de Almeida

Nonlinearity ***13*** *(2000) 341*

In this work we study cat maps with many degrees of freedom. Classical cat maps are classified using the Cayley parametrization of symplectic matrices and the closely associated center and chord generating functions. Particular attention is dedicated to loxodromic behavior, which is a new feature of two-dimensional maps. The maps are then quantized using a recently developed Weyl representation on the torus and the general condition on the Floquet angles is derived for a particular map to be quantizable. The semiclassical approximation is exact, regardless of the dimensionality or of the nature of the fixed points.

"Semiclassical quantization with short periodic orbits"

E.G Vergini and G.G Carlo

J.Phys. ***A 33*** *(2000) 4717*

We apply a recently developed semiclassical theory of short periodic orbits to the stadium billiard. We give explicit expressions for the resonances of periodic orbits and for the application of the semiclassical Hamiltonian operator to them. Then, by using the 3 shortest periodic orbits and 2 more living in the bouncing ball region, we obtain the first 25 odd-odd eigenfunctions with surprising accuracy.

"Semiclassical Theory of Short Periodic Orbits in Quantum Chaos"

E.G Vergini

J. Phys. ***A33*** *(2000) 4709*

We have developed a semiclassical theory of short periodic orbits to obtain all quantum information of a bounded chaotic Hamiltonian system. If T_1 is the period of the shortest periodic orbit, T_2 the period of the next one and so on, the number $N_{p,o}$ of periodic orbits required in the calculation is such that $T_1+...+T\ N_{p,o} \cong T_H$, with T_H the Heisenberg time. As a result $N_{p,o} \cong h\ T_H\ \Lambda\ \ln(h\ T_H)$, where h is the topological entropy. For methods related to the trace formula $N_{p,o} \cong \exp(h\ T_H)/(h\ T_H)$.

"Classical invariants and the quantum-classical link"

D. Wisniacki and E. Vergini

Phys. Rev. ***E62*** *(2000) R4513*

The classical invariants of a Hamiltonian system are expected to be derivable from the respective quantum spectrum. In fact, semiclassical expressions relate periodic orbits with eigenfunctions and eigenenergies of classical chaotic systems. Based on trace formulae, we construct smooth functions highly localized in the neighborhood of periodic orbits using only quantum information. Those functions show how classical hyperbolic structures emerge from quantum mechanics in chaotic systems. Finally, we discuss the proper quantum-classical link.

“Beyond the First Recurrence in Scar Phenomena”

D. Wisniacki, F. Borondo, E. Vergini and R.M. Benito

Phys. Rev. ***E 62*** *(2000) R7583*

The scarring effect of short unstable periodic orbits up to times of the order of the first recurrence is well understood. Much less is known, however, about what happens past this short-time limit. By considering the evolution of a dynamically averaged wave packet, we show that the dynamics for longer times is controlled by only a few related short periodic orbits and their interplay.

“Wiggly Strings in Linearized Brans-Dicke Gravity”

A. Arazi and C. Simeone.

Mod. Phys. Lett. ***A15 (21)*** *(2000) 1369*

The metric around a wiggly cosmic string is calculated in the linear approximation of Brans-Dicke theory of gravitation. The equations of motion for relativistic and non-relativistic particles in this metric are obtained. Light propagation is also studied and it is shown that photon trajectories can be bounded.

“Cylindrical Sources in Full Einstein and Brans-Dicke Gravity”

A. Arazi and C. Simeone.

General Relativity and Gravitation ***32 (12)*** *(2000) 2259*

It was shown by Hiscock that the energy-momentum tensor commonly used to model local cosmic strings in linearized Einstein gravity can be extended and used in the full theory, obtaining a metric in the exterior of the source with the same deficit angle. Here we show that this tensor is an exception within a family for which a static solution does not exist in full Einstein nor in Brans-Dicke gravity.

“Global Phase Time and Path Integral for the Kantowski-Sachs Anisotropic Universe”

C. Simeone

General Relativiy and Gravitation ***32 (9)*** *(2000) 1835*

The action functional of the anisotropic Kantowski--Sachs cosmological model is turned into that of an ordinary gauge system. Then a global phase time is identified for the model by imposing canonical gauge conditions, and the quantum transition amplitude is obtained by means of the usual path integral procedure of Fadeev and Popov.