Report of MARIO NOVELLO (2013)

List of papers and some comments on the lines of research I have been developing and the ones I shall be developing in the coming years.

1. ***Gordon Metric Revisited,*** M. Novello and E. Bittencourt, to be published in *Phys.Rev. D.*

We show that Gordon metric belongs to a larger class of geometries, which are responsible to describe the paths of accelerated bodies in moving dielectrics as geodesics in a metric $\hat q_{\mu\nu}$ different from the background one. This map depends only on the background metric and on the motion of the bodies under consideration. As a consequence, this method describes a more general property that concerns the elimination of any kind of force acting on bodies by a suitable change of the substratum metric.

2. ***What is the origin of the mass of the Higgs boson?*** M. Novello and E. Bittencourt, *Phys.Rev. D86 (2012) 063510.*

The purpose of this paper is to present a unified description of mass generation mechanisms that have been investigated so far and that are called the Mach and Higgs proposals. In our mechanism, gravity acts merely as a catalyst and the final expression of the mass depends neither on the intensity nor on the particular properties of the gravitational field. We shall see that these two strategies to provide mass for all bodies that operate independently and competitively can be combined into a single unified theoretical framework. As a consequence of this new formulation we are able to present an answer to the question: what is the origin of the mass of the Higgs boson? This paper is a continuation of the program of the analysis of the mechanisms of mass generation that was started in 2011 with the work presented in CQG entitled:

3. ***The gravitational mechanism to generate mass.*** M. Novello, *Classical and Quantum Gravity v. 28, p. 035003, 2011.*

Given the imminent possibility of proving or disproving the existence of Higss boson by experiments currently underway at CERN (European Organization for Nuclear Research), it is time to non-dogmatically examine the different proposals around the origin of the mass of all bodies. This paper looks into two of the most relevant mass generating mechanisms developed by scientists. I have emphasized the mechanism of gravitational origin for a couple of reasons. First, because Higgs's concurring mechanism has been vastly presented and described in various publications. Second, because there is a novelty in that proposal that makes it particularly attractive thanks to the discovery that the traditional difficulties presented against the gravitational mechanism have been eliminated, turning this into a most acceptable mass generating mechanism for all bodies.

4. **Extended Born-Infeld theory and the bouncing magnetic universe**. M. Novello, J. M. Salim, and Aline N. Araújo, *Phys. Rev. D 85, 023528 (2012)*

We show that a generalized Born-Infeld electrodynamics responsible for regular configurations of the static field of a charged particle produces a nonsingular universe that contains a bouncing. This means that the Universe has a previous collapsing phase, attains a minimum value for its scale factor and then enters into an expanding phase. We exhibit such a scenario in the case of an average pure magnetic universe. At its infinity past as well as at its infinite future the distribution of the energy content of the magnetic fluid displays the form of a cosmological constant. Thus such a configuration is an intermediary between asymptotic vacuum states. In other words, this magnetic universe evolves from vacuum to vacuum.

5. **Dragged metrics**. M. Novello and E. Bittencourt, *arXiv:physics.gen-ph:1201.2806*

We show that the path of any accelerated body in an arbitrary space-time geometry $\hat g_{\mu\nu}$ can be described as geodesics in a dragged metric $\hat q_{\mu\nu}$ that depends only on the background metric and on the motion of the body. Such procedure allows the interpretation of all kind of non-gravitational forces as modifications of the metric of space-time. This method of effective elimination of the forces by a change of the metric of the substratum can be understood as a generalization of the d'Alembert principle applied to all relativistic processes.

6. **A geometrical origin of the right-handed neutrino magnetic moment**. M. Novello and E. Bittencourt, *arXiv:physics.gen-ph:1111.2347*

We propose a new form of contribution for the anomalous magnetic moment of all particles. This common origin is displayed in the framework of the recent treatment of electrodynamics, called Dynamical Bridge Method, and its corresponding introduction of an electromagnetic metric which has no gravitational character. This electromagnetic metric constitutes a universal process perceived by all bodies, charged or not charged. As such it yields automatically a conclusive explanation for the existence of a magnetic moment for the right-handed neutrino.

7. **Hidden geometries in nonlinear theories: a novel aspect of analogue gravity**. E.Goulart, M. Novello, F.T.Falciano and J.D. Toniato, *Classical and Quantum Gravity 28, 245008 (2011)*

We show that non-linear dynamics of a scalar field ϕ may be described as a modification of the spacetime geometry. Thus, the self-interaction is interpreted as a coupling of the scalar field with an effective gravitational metric that is constructed with ϕ itself. We prove that this process is universal, that is, it is valid for arbitrary Lagrangian. Our results are compared to usual analogue models of gravitation, where the emergence of a metric appears as a consequence of linear perturbation.

8. **Electromagnetic Geometry**. M. Novello, F. T. Falciano and E. Goulart, *arXiv:physics.gr-qc:1111.2631*

We show that Maxwell's electromagnetism can be mapped into the Born-Infeld theory in a curved space-time, which depends only on the electromagnetic field in a specific way. This map is valid for any value of the two Lorentz invariants F and G confirming that we have included all possible solutions of Maxwell's equations. Our result seems to show that specifying the dynamics and the space-time structure of a given theory can be viewed merely as a choice of representation to describe the physical system.

Some related papers:

9. **Beyond analog gravity: the case of exceptional dynamics**. M. Novello and E. Goulart, *Classical and Quantum Gravity 28, 145022 (2011)*.

Up until recently, the idea of using scalar and/or vector fields to mimic gravitational processes was limited to kinematic issues. This meant that the propagation processes of these fields that satisfy non-linear theories may be described by a change in the geometry of space-time, mimicking gravitational effects, in terms of effective metrics. This used to be done only in issues referring to kinematics rather than dynamics.

Ever since this article I wrote with my collaborator E. Goulart, this situation has changed, for we have been able to show that there are exceptional dynamics where the very dynamics is written as a function of the effective metrics. The next step—which we have already taken—is to extend this result to other dynamics of the scalar field, and, at a second moment, to vector fields. This is one line of research I will develop.

A doctorate student, Junior Toniato, will join this study, as well as post-doctorate E. Goulart and my collaborator Felipe Tovar Falciano.

Some related papers are

10. **Gaussian coordinate systems for the Kerr metric**. M. Novello and E. Bittencourt, *Gravitation & Cosmology 17, 3 (2011)*.

Generating a most important geometry, Kerr metric is certainly one solution to equations in the field of general relativity in emptiness. It has been used hundreds of times to understand mechanisms associated with processes in Astrophysics involving non spherically symmetric black holes (with an axis of symmetry and rotation). In all of these studies and everywhere in the related scientific literature (that is, in all books on gravitation and/or astrophysics) this metric is described in various forms, always explicitly involving cross terms or terms in null coordinates. In this paper, we explicitly exhibit a class of Gaussian systems of coordinates and the different domains of its validity and extensions. Based on this description, the quasi-Maxwellian formulation of this geometry may be developed in a practical and accessible manner. Gauge's independent formalism may then be used to examine its perturbation, be it by introducing matter or by propagating gravitational waves. This is what we are doing in my student Bittencourt's doctorate thesis.

11. **Reproducing gravity through spinor fields**. M. Novello and Maria Borba, *Gravitation & Cosmology 17, 224 (2011)*.

Another line of investigation involves a more fundamental question, related to some aspects of the General Relativity theory, which I describe in the previous report, by the paper:

12. **A Spinor theory of gravity and the cosmological framework**. M. Novello, *JCAP 0706:018 (2007). ArXiv gr-qc/0701120.*

In this paper, which is the continuation of my student Maria Borba's master thesis, we show how a static and spherically symmetric geometry can be obtained as a solution to my equations in the Spinorial Theory of Gravitation.

13. **On a Geometrical Description of Quantum Mechanics**. M. Novello, F.T. Falciano and J.M. Salim, *International Journal of Geometric Methods in Modern Physics 8, 87 (2011)*.

14. **Geometrizing relativistic quantum mechanics.** M. Novello, F.T. Falciano and J.M. Salim, *Foundations of Physics 40, 1885 (2010)*.

In these two papers I have developed with my collaborators an old Gordon idea, according to which there would be a close relation between gravitational processes and the metric structure of space-time. However, in the traditional formulation of Quantum Mechanics and its support on the Copenhagen interpretation, this Gordon idea did not find any possibility to be implemented. So, using deBroglie and Bohm's formulation, we could associate quantum processes to changes in rulers and clocks of classical objects and understand these effects in a structure we call QWIST (Quantum Weyl Integrable Spacetime), meaning quantum effects would be but the outcome of change to a Riemannian structure, where scales of space and time length do not vary in their space-time configuration for a particular geometry of Weyl: that which enables a definition of variable space-time lengths.

This result was restrained to the treatment of a particle that satisfies the Schrodinger equation (non-relativistic case) or the Klein-Gordon equation (relativistic case). We shall address situations involving more than one particle in the near future.

15. **The spectrum of scalar fluctuations of a bouncing universe.** Marcela Campista, J. M. Salim and M. Novello, *International Journal of Modern Physics A 25, 3095 (2010)*.

In this paper we proceed with our analysis referring to observable properties and characteristics of cosmological models with bouncing, that is, geometries that represent universes with a collapsing phase prior to the current expanding phase. The idea is to confront results from the evolution of the fluctuations in models with initial singularity and models without singularity, and particularly those with bouncing.

This paper will continue, involving other types of perturbations (vector, with vortices and gravitational waves, besides neutrinos).

16. **Gravitational waves in singular and bouncing FLRW universes**. V. Antunes, E. Goulart and M. Novello, *Gravitation & Cosmology 15, 191 (2009)*.

With a methodology that is totally different from number 9 above, we now look at observable distinctions that would be associated with the propagation of gravitational waves in cosmological models with initial singularity and models without singularity, and particularly those with bouncing. In this paper we examine the phase space of possible configurations as well as their associated topologies. We show that this topological exam can perfectly distinguish both scenarios through the evolution of gravitational waves.

17. **Cyclic Magnetic Universe**. M. Novello, Aline N. Araújo and J.M. SALIM, *International Journal of Modern Physics A 24, 5639 (2009)*.

Proceeding with our investigation of the consequences to Cosmology of non-linear processes of the electromagnetic field, we show how it is possible to generate cyclical models of the universe from averages over the fields (of the conventional type, as is done in the very application of Maxwell's linear theory on the basis of Tolman's proposal). We particularly exam cases where only the averages of magnetic field survive—cases where the primordial fluid is described as a plasma.

18. **Bouncing Cosmologies**. M. Novello and S. E. P. Bergliaffa, *Physics Reports 463, 127 (2008)*.

In this paper we make a thorough review of all proposed cosmological models without singularity and containing a bouncing. We examine both the classical processes of avoiding singularity and the modes that use effects of a quantum nature, be it of the matter or of the very gravitational field. As we examine more than 500 papers, we casually discovered an interesting curiosity worthy of a note: the first complete analytical solution of a cosmological model with bouncing was made by two Brazilians, Mário Novello and José Martins Salim, in 1969.

Some extra references to the previous list of papers

- **Cosmological effects of nonlinear electrodynamics**. M. Novello, *Int. J. Mod. Phys. A 20, 2421 (2005)*.
- **A toy model of a fake inflation**. Mario Novello, E. Huguet and J. Queva, *Phys. Rev. D 73, 123531 (2006)*.
- **Extended Born-Infeld dynamics and cosmology**. M. Novello, Martin Makler, L.S. Werneck and C.A. Romero, *Phys. Rev. D 71, 043515 (2005)*.
- **Constructing Dirac linear fermions in terms of non-linear Heisenberg spinors**. M. Novello, *Europhysics Letters 80, 41001 (2007)*. ArXiv:0705.2692 astro-ph.
- **Cosmological Effects of Nonlinear Electrodynamics**. M. Novello, E. Goulart, J.M. Salim, S. E. Perez-Bergliaffa, *Class. Quant. Grav. 24, 3021 (2007). Arxiv: gr-qc/0610043*
- **The Nature of Lambda and the mass of the graviton: a critical view**. J. P. Gazeau and M. Novello, *arxiv: gr-qc/0610054.*

Ongoing Doctorate Advisor to:

Vicente Antunes

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Organization of schools and international scientific events:

A) XV Brazilian School of Cosmology and Gravitation (from August 19 to September 1) held in Mangaratiba, RJ (2012).

B) Primeira Reunião Argentino-Brasileira de Gravitação (from October 04 to October 08) held in Foz do Iguaçu (2011).

C) Mário Novello's 70th Anniversary Symposium (from August 15 to August 17) held in Rio de Janeiro (2012).

D) Workshop in honour to the 70 years of Prof. Sérgio Joffily (August 3) held in Rio de Janeiro (2012).

E) I Symposium Mário Novello on Bouncing Models (from November 26 to November 30) held in Mangaratiba, RJ (2010).

Books published (besides Conference Procceedings and the Brazilian School of Cosmology and Gravitation):

i) **Eletrodinâmica não linear (causalidade e efeitos cosmológicos)** in collaboration with Érico Goulart. Published in the CBPF collection by Editora Livraria da Física.

ii) **Cosmologia**. Published in the CBPF collection by Editora Livraria da Fisica.

iii) **Do big bang ao universo eterno**, a promotion book published by Editora Jorge Zahar.

iv) **Qualcosa anziché Il nulla (La rivoluzione del pensiero cosmológico)**. Translation into Italian of my epistemology book "O que é Cosmologia?" (Ed. Jorge Zahar) published in 2011 by Editora Einaudi (Torino and Milan).

Publication of Conference Proceedings

1) Cosmology and gravitation. **Proceedings of 14th Brazilian School of Cosmology and Gravitation 2010**, Mangaratiba, Brazil, (from August 30 to September 11). Mario Novello and Santiago E. Perez Bergliaffa (editors), 431p. (2012).

2) **Mach or Higgs? The Mechanisms to generate mass**. M. Novello, Aug. 2010. 35pp. Presented at 14th Brazilian School of Cosmology and Gravitation. ArXiv: physics.gen-ph 1008.2371

3) Cosmology and gravitation. **Proceedings of 13th Brazilian School of Cosmology and Gravitation 2008**, Mangaratiba, Brazil, (from July 20 to August 02). Mario Novello and Santiago E. Perez-Bergliaffa (editors), *AIP Conf. Proc. 1132, 442 p (2009).*

4) **Proceedings of the II Conferência de SOBRAL – The Sun, the stars, the universe and general relativity**, *American Institute of Physics, New York, (2010).*

5) **A model for mass generation based on gravitation**, M. Novello, *in XIV LISHEP conference, July 6, (2011).*

6) **Reproducing gravity through spinor fields**. M. Novello and Maria Borba, *Gravitation & Cosmology 17, 224 (2011)*. The latter is a part of the "Lectures Notes" on STG that I prepared

for a course in November 2010, invited by the organizing committee of the Marseille School of Cosmology, of the Centre de Physique Théorique.

A brief summary of the lines of research:

- Scalar Theory of Gravitation;

In recent years a few papers have appeared reviewing the scalar theory of gravity and pointing out the reasons for which that theory was dismissed (see \cite{gibbons}, \cite{giulini} and \cite{will} and references therein for a fairly complete review on scalar theories of gravity). Criticisms range from theoretical to observational; they are based on the hypothesis made since the old days of the Einstein-Grosmann proposal \cite{coll-eins} that scalar gravity deals with essentially three assumptions:

  - The theory is described in a conformally flat geometry and the background Minkowski metric is observable;
  - The source of the gravitational field is the trace of the energy-momentum tensor;
  - The scalar field is the relativistic generalization of the Newtonian potential.

In this paper we present a new possibility for describing the gravitational interaction in terms of a scalar field Φ, i.e. a geometric scalar gravity (GSG). The above three assumptions do not hold in our theory. In particular, we shall see that the general belief that the only possible source of scalar gravity is the trace of the energy-momentum tensor is not valid here.

Let us clarify from the very beginning that this is not a special relativistic scalar gravity. The adjective geometric in the title pinpoints it similarity with general relativity: we are constructing a metric theory of gravity. In other words, we follow the main idea of general relativity and assume as an \textit{a priori} that gravity is described by a Riemannian geometry. In general relativity the ten components of the metric tensor are the basic variables of the theory (up to diffeomorphism invariance). Here the metric tensor is determined by the derivatives of a fundamental independent physical quantity represented by the scalar field $ \Phi.$ This means that although we propose a scalar field to represent all gravitational processes we do not follow the previous examples of scalar gravity, as for instance the Einstein-Grossman ``Entwurf Theory''. Before presenting the reasons that motivated us to undertake this proposal, let us summarize the main properties of the GSG:

  - The gravitational interaction is described by a scalar field $ \Phi$;
  - The field Φ satisfies a nonlinear dynamics;
  - The theory satisfies the principle of general covariance. In other words this is not a theory restricted to the realm of special relativity;
  - All kind of matter and energy interact with Φ only through the Riemannian metric $q_{\mu\nu} = a\eta_{\mu\nu}+b\partial_{\mu}\Phi \partial_{\nu} \Phi$;
  - Test particles follow geodesics relative to the gravitational metric $ q_{\mu\nu};$
  - Φ is related in a nontrivial way with the Newtonian potential Φ_N;

- Electromagnetic waves propagate along null geodesics relative to the metric $q^{\mu\nu}.$

The parameters a and b are functionals of the scalar field Φ (which will be specified by fixing the Lagrangian of the scalar field). It then follows that the auxiliary (Minkowski) metric $\eta^{\mu\nu}$ is unobservable because the gravitational field couples to matter only through $q^{\mu\nu}$. Here we follow the main steps of general relativity where a unique geometrical entity interacts with all forms of matter and energy and the geometry underlying all events is controlled by the gravitational phenomena.

From this postulate it follows immediately that the space-time geometry is an evolutionary process identified to the dynamics of the gravitational field. This beautiful hypothesis of general relativity is contained in each observation as a specific example of a geometry solving that dynamics.

The second important postulate of general relativity states that the metric couples universally and minimally to all fields of the standard model by replacing everywhere the Minkowski metric $\eta_{\mu\nu}$ by $g_{\mu\nu}.$

We will accept also this postulate, but we investigate a special form for the Riemannian metric that represents the gravitational field. We shall describe the origin of this departure from general relativity in a later section after reviewing in the next section the case of general relativity.

A final remark concerns our method to identify the right form of the dynamics of the scalar field. The action of a given theory is generally constructed using certain a priori principles and rules. For instance one might want to impose general covariance, symmetry principles such as the gauge principle and a limitation on the order of derivatives. Although these principles are preserved in our theory they are of course not enough. Here we adopt observation-oriented procedure and try to determine the form of the dynamics of our GSG as a power expansion in the field Φ whose coefficients are fixed from observations. This means that we try to proceed step by step, adding new terms to the Lagrangian when observation imposes this, and we continue such procedure until the theory achieves its final form. In the following we present an example of how this strategy can be used by the analysis of the motion of test particles (like planetary orbits) in the field generated by a massive body like the sun in the quasi-linear regime.

- Effective Geometry (kinematic and dynamic aspects);

    - Analog models of the general relativity

In 1998, CBPF's Gravitation and Cosmology Group (currently ICRA) started a systematic analysis of the propagation of photons in theories of non-linear electromagnetism (NLEM) and in the presence of media with dielectric properties dependent upon an external field. Most of this work was done in the area of analog models of gravitation. These models seek to replicate in laboratory gravitational configurations using non gravitational systems, such as Bose-Einstein's condensates, ordinary fluids without viscosity and with dielectric properties, and non-linear electromagnetism in vacuum (see, for instance, the proceedings from the Workshop on Aritificial Black Holes). Various important results have been obtained by our group in this area: closed timelike curves for the photons, electromagnetic wormholes, and analog black holes. The latter could be built in the laboratory to test some theoretical predictions. In particular, the electromagnetic black hole proposed by our group would emit laboratory detectable Hawking's radiation, which would allow us to confirm a crucially important result in Quantum Theory of Fields in curved space-time.

The effective metric appears in systems of varied nature, when the subjacent dynamics changes the structure of the geometry in such way that the geometry where the highest energy excitations of the field (whether photons, phonons, etc) move is no longer that of the background. One such system is a non-linear electromagnetic field, originated by the effects of QED vacuum polarization.

- Analog Black Holes – Photon propagation in material media

The propagation of electromagnetic waves through vacuum is a well determined phenomenon by Maxwell's set of equations, which are second order partial differential equations. However, special care is needed to characterize the propagation of those waves in non-trivial media, as when the electromagnetic field reaches its critical value or in material media. A complicated set of differential equations will have to be involved, in general and for every case to be studied. For the case of non-linear electrodynamics, Dittrich and Gies obtained the conditions over the cones of light for a class of theories with a non-trivial vacuum structure. Using a rule known as polarization sum, these authors obtained but the average speed of waves. Important aspects about wave propagation are not described, such as the effect of the optical birefringence, where a different wave speed will be associated to each polarization mode. Using a different procedure, members of our group obtained the conditions over the cones of light associated with the propagation of electromagnetic waves to non-linear theories without imposing any restriction upon the polarization modes. The same authors developed a geometric interpretation for the propagation of waves, showing that these waves travel over null geodesic in an effective geometric structure, determined on the basis of the conditions over the cones of light. The importance of this geometric formulation consists of the possibility to compare effects that occur with the propagation of light in non-trivial situations with kinematic aspects coming from the theory of general relativity. A most burning question about this issue is whether there are ways in which to obtain material structures that may exhibit a horizon of events, similar to what has been described by the Schwarzschild solution in Einstein's theory of gravitation.

In order to answer the questions above, the first investigation to take place involves determining the equations governing the propagation of electromagnetic waves in material media and the geometric description associated with this propagation. In this situation, Maxwell's traditional equations must be re-written, with the introduction of constitutive relations that relate the electromagnetic field (E, H) with the fields induced in the material medium (D, B). In general, constitutive relations may be presented in the tensor form, ensuring the possibility of studying even propagation in anisotropic media.

It is important to notice that, up until recently, only kinematic aspects of the General Relativity could be mimicked as such, without describing its dynamic properties.

The most relevant of the results obtained previously includes the possibility of producing a non-gravitational Black Hole (NGBH) in laboratory through non-linear electromagnetic processes.

Recently, my collaborator Erico Goulart and I managed to show, in **Beyond Analog Gravity: The Case of Exceptional Dynamics** (in *Class. Quant. Grav. 28 145022 (2011); arXiv:1102.1913 [gr-qc]*), that it is possible to go beyond the mere kinematic characteristics which are typical of the analog models studied this far, including the very dynamics of the process. This was done for the case of a scalar field and our purpose on this line of research is to advance as much for the electromagnetic field, be it in non-linear field theories or in non-linear dielectric media.

Recent studies I have been developing with collaborators in my research group have shown the important role non-linear Electrodynamics may play in crucial Cosmology issues, involving moments in the history of the evolution of the Universe, referring to regimes of high and low curvature (very intense and very weak gravitational fields), that is, for an extremely condensed state of the universe and in the acceleration phase.

- Cosmological models with bouncing;

In a series of paper, we show that a strong magnetic field, in various theory examples of Non-Linear Electrodynamics (NLE), is capable of avoiding the primordial cosmologic singularity, which is present and inevitable in Maxwell's linear theory. It concerns the change of field behavior in extremely strong field regions.

An extensive analysis made with my collaborator SEP Bergliaffa, in a paper published in Physics Reports (**Bouncing Cosmologies**. M. Novello and S. E. Perez-Bergliaffa, *Phys. Rept. 463, 127 (2008); arXiv:0802.1634 [astro-ph]*), we examine the different scenarios without singularity proposed in Cosmology. In this project, I will continue to address these as well as other related issues.

In the past decades, an overwhelming amount of astronomic information involving the detection of highly energetic particles, gravitational lenses and other astrophysics processes has changed the Astrophysics and Cosmology scenario in great depth. The Theory of General Relativity (TGR) constitutes the Modern Theory of Gravitation. However, many of its consequences have not been strictly observed (such as gravitational waves, for instance), and there are some critical situations where the TGR does not seem to apply and needs modifications or generalizations. These situations are i.) final stage of certain stellar evolutions, and ii.) primordial Cosmology (the issue of singularity and initial conditions of the Universe).

Along the 1970's, the problem of singularity has become the major issue in Cosmology. The hypothesis of such singularity, at a finite time of our epoch, the discomforting consequence that it is not possible for us to know the initial data of the universe! It limits the possibility of obtaining a complete cosmologic description, similar to what happens with black holes. Firstly, the existence of a primordial singularity was considered a definitive datum, thanks to the high status acquired by a series of theorems. The latter, demonstrated in the realm of General Relativity, seemed to show Classical Physics' impossibility to produce non-singular gravitational configurations. This was the main reason for more careful examinations of quantum aspects in Cosmology. However, along the 1980's, different approaches—conceived in areas such as Thermodynamics outside equilibrium or other approaches involving different forms of coupling fields of matter with gravitation—produced effective alternatives to solve this problem, as they generated non-singular cosmologic solutions. These results have originated a new and profound line of investigation on the properties of the Universe in its extremely condensed but non-singular phase.

Thanks to improved observation techniques, current data quality enables much more precise comparisons with theoretical predictions. The interaction between theory and observation has thus become much more intense in the past few years, particularly in Cosmology. For instance, by analyzing the distribution of matter and studying the spectrum of power of Cosmic Microwave Background Radiation, one may test theories that describe the primordial Universe and understand the evolution mechanisms of initial fluctuations. Thus, a model that predicts an eternal Universe rather than an initial singularity, for instance, produces a signature on the large scale structure that may be sought through current data. A central objective of this project is to study this interrelation between the dynamics of the structures of the Universe and the very structure of space-time, that is, of gravitation.

The theory of perturbation, which describes the fluctuations that originate the large scale structure and anisotropy in the cosmic background radiation, has been the object of intense investigation by our group. The non-linear evolution of the structures, a more advanced evolutionary stage of the fluctuations, is also being studied. Observable effects of the quantum nature of space-time are equally being derived, just as the relation between gravitational waves and neutrinos in the context of neutrino oscillations in the explosion of supernovas. I shall develop these lines in an integrated manner, focused on obtaining amounts that can be measured in space or in the laboratory.

- Gravitational Mechanism for the Generation of Mass;

In order to become a reliable candidate as a mechanism to generate mass, there are three indispensable conditions that such mechanism has to fulfil, to wit:

  - There must exist a universal field that interacts with all kinds of particles;
  - This field must be such that its interaction with matter breaks explicitly some symmetry that only massless particles exhibit, e.g. the gauge freedom for vector fields or the chirality for fermions;
  - There must exist a free parameter such that different bodies can acquire distinct values for their corresponding mass (the spectrum of mass).

There are only two fashionable candidates that fulfill the first condition:

  - The gravitational field;
  - A scalar field ϕ.

The Higgs boson ϕ was postulated to couple universally with all kinds of matter. The other candidate, gravity, is known to couple with all forms of matter and energy and its universality is recognized as a scientific truth. We note that after accepting either one of these two fields as a good candidate that fulfills the first requirement, it is not a hard job to elaborate scenarios such that the other two conditions are satisfied too. We would like to compare these two mechanisms and analyze the conditions under which their strategies can be combined.

- Geometric interpretation of the quantum theory via Bohm-deBroglie formulation.

The early years of quantum mechanics were marked by intense debates and controversies related to the meaning of the new behavior of matter. While one group was convinced that was unavoidable to abandon the classical picture, the other group tried incessantly to save its main roots and conceptual pillars. To be able to reproduce the atypical quantum effects, the latter group was forced to introduce new ingredients such as de Broglie’s pilot wave or Mandelung’s hydrodynamical picture.

However, the lack of physical explanations for these ad hoc modifications weakened these pictures. At the same time, the former group leaded by Schrödinger, Bohr and Heisenberg was increasingly gaining new adepts until its climax in the 1927 Solvay’s conference when this picture was finally accepted as the orthodox interpretation of quantum mechanics - the Copenhagen interpretation.

Notwithstanding, a marginal group of physicists continued to develop other approaches to describe quantum mechanics that are more adequate to connect to a classical picture. One of the most prominent amongst these alternative interpretations is the causal interpretation of quantum mechanics also known as Bohm-de Broglie interpretation.

The development of quantum cosmological scenario brought to light some difficulties intrinsic to the Copenhagen interpretation. More specifically, the measurement process in a quantum closed universe seems inevitably inconsistent. Fortunately, there are some alternative interpretations that are consistently applied simultaneously to cosmology and to the micro-world. As two examples we mention the many-worlds interpretation and the consistent histories formulation.

Synthesizing these lines of research:

The Eternal Universe: This is an attempt to answer the challenging question as to whether the universe had a singular start at a point of maximum condensation, as admitted in Cosmology's standard model, or whether it would have collapsed from a large volume down to a minimum value, different from zero, and then moved into an expansion phase.

Scalar Theory of Gravitation: The difficulties to reconcile observations of Supernovas with Friedmann's equations have led to a review of the fundamentals of the theory of gravitation. One such possibility is being studied by our group and has been given strong support when professor M Novello visited the ICRA in Italy, both to the ICRANet headquarters in Pescara and to the La Sapienza University in Rome.

Dark Energy: Observations made in 1998 with distant Supernovas suggests that the universe could be in a phase of accelerated expansion. Interpreted in accordance with the theory of relativity, these surprising results suggest that there must be negative pressures dominating the dynamic evolution of the universe. Besides bringing Einstein's cosmological constant to consideration, they create a series of burning questions that challenge Cosmology and Astrophysics. This line of research is intended on studying unconventional forms of high negative pressure energy in order to contribute to enhance knowledge about its nature, mechanisms and role in the evolution and structure of the universe.

Artificial Black Holes: Under certain circumstances, it's been observed that non-universal processes such as the propagation of electromagnetic and sound waves as well as some particularities of liquid helium may be described as special consequences of geometry modifications associated with the medium where these phenomena occur. It is thus possible to produce configurations of a non-gravitational nature, such as special cases of gravitational fields. Called "Analog Models", this method allows us to mimic the behavior of gravitational fields in laboratory, including the creation of a Black Hole (electromagnetic?). This type of investigation may enable future testing of some gravitational black hole properties, including the theoretical possibility of radiation emission.

Origin of galaxies and galaxy clusters: The universe is organized in billions of galaxies; and each one, in hundreds of billions of stars. Galaxies, in their turn, are organized in clusters. These hugely immense structures originated from small deviations from the high homogeneity existing in the early moments and grew due to the attractive nature of gravitation. These minuscule deviations have admittedly resulted from quantum fluctuations of matter and the gravitational field. Recent observations enable a distinction between different competitive mechanism, capable of generating those primordial seeds of inhomogeneities. This line of research is based on the idea of producing a theoretical model capable of building a realistic scenario that is compatible with data from the observation.

I add here some selected articles that appeared this year:

http://arxiv.org/PS_cache/arxiv/pdf/1111/1111.2631v1.pdf
http://arxiv.org/PS_cache/arxiv/pdf/1111/1111.2347v1.pdf

http://arxiv.org/PS_cache/arxiv/pdf/1108/1108.6067v1.pdf
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