IRAP PHD REPORT

A new Era in Relativistic Astrophysics

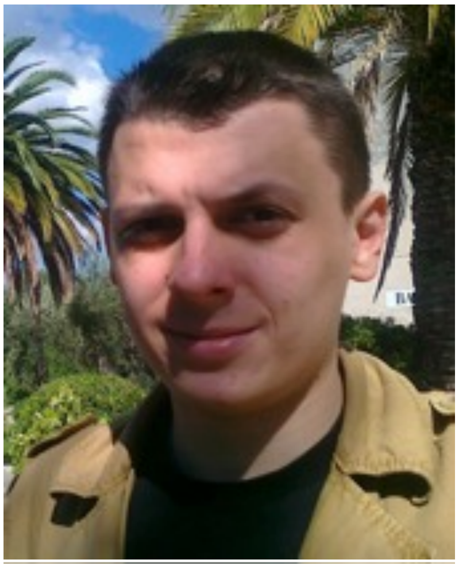
Consortium Meeting

Nice, May 30 2011

Andrey BARANOV (Russian)

Supervisor: Prof. P. Chardonnet

University of Savoie



Research Activities

The title of my thesis is "**Pair instability supernovae explosion and gamma-ray bursts**". Gamma-Ray Bursts (GRBs) are very high energetic bursts of gamma emission that last for a few seconds and come from very distant parts of the Universe. They are already known from 1960s, but until now there is no self-consistent description of this phenomenon. Still there is no definite answer on the question "Which objects are the source of GRBs?". The purpose of my work with prof. Chardonnet is to check if GRBs could be explained as a result of explosion of a very massive star. This kind of stars undergoes specific kind of instability which is called "pair instability". This instability could lead to an explosion of a whole star and then this star becomes "pair-instability supernova". Recently this type of supernova was only theoretical model but a few years ago observational evidences of existence of these phenomena were obtained.
To analyze these complex phenomena we need to make numerical simulations. To do these simulations I developed computer code for spherically symmetrical model of explosion. This simple spatial model allowed us to concentrate on microphysical processes inside the star and to understand which of them should be introduced inside our computational model. At this moment we obtained first results which were presented on Erasmus Mundus Workshop in Les Houches, France. And now we are working under the complication of our computational model and introducing more physics inside it. It will help us to perform further analysis and to compute spectra and time-variability of emission – the quantities that could be compared with observational data.

Why I recommend this Program

IRAP PhD program is great opportunity to start or continue scientific work in astrophysics. First of all it provides interesting topics of research from different fields of astrophysics. And it is already great, because modern astrophysics is very wide area of science. Despite research activity, it provides great collaboration activity, which is very important. We have schools twice a year, workshops and meetings, where we meet experts from various fields of astrophysics. All this helps to make new connections within scientific community.

Alberto BENEDETTI (Italian)

Supervisor: Prof. R. Ruffini

University of Roma

Research Activities

The title of my thesis is: ”**Emission from the photosphere of Gamma-Ray Bursts (GRBs): kinetic approach**”. GRBs are high energy astrophysical phenomena that happen in a short time, from a few to tens of seconds. All the informations about them come from the photons we can observe with our instruments. The goal of my research is to explain the features of the light produced and emitted from the photosphere. The photosphere is a surface where photons are scattered for the last time before starting to propagate toward the observer; besides it is expanding with a speed close to the speed of light. Within the kinetic approach we adopt, the microphysical interactions can be taken into account in detail, allowing us to calculate the physical quantities related to the light detected by the instruments.

At the beginning of my PhD I moved to Rome at the University of La Sapienza where I began to study the Relativistic Kinetic Theory, as the necessary theoretical background of my research topic, and I followed the lectures of prof. Ruffini on General Relativity. In parallel to that and in collaboration with my tutor Dr. Vereshchagin, I started a work related to the behavior of the electron-positron pairs when they are produced in a strong electric field; the result of this work has been published on the Physics Letters B Journal. Then I started to work out the set of equations we need for our model. However, due to the complexity of the problem, a numerical code is essential. For this reason part of my activity has been devoted to the understanding and improvement of the code provided my Dr. Aksenov with whom I collaborate as well.

Why I recommend this Program

We have the opportunity to interact with professors and students experienced not only in the field of relativistic astrophysics but also in a wide range of other related topics. This gives us the chance to study and work deeply on a specific subject but also understanding what is happening around it. The relativistic astrophysics is in a continuously evolving state, therefore an overall point of view can help us understanding our future perspectives.
The program is just started and we have the possibility to improve it presenting our suggestions and ideas: a good possibility to collaborate all together in order the make it more advantageous and fruitful for everybody.

Parikshit DUTTA (Indian)

Supervisor: Prof. H. Nicolai

Albert-Einstein-Institute

Research Activities

The title of my thesis is "**N=4 SuperSymmetric Yang Mills Theory**". I work under the supervision of Prof. Hermann Nicolai at the Albert Einstein Institute in Potsdam. We look at the N=4 SuperSymmetric Yang Mills Lagrangian in 4 dimensions, which is special as it is finite, i.e. it is free from ultraviolet divergenges and needs no renormalization unlike most other field theory models. In this case we try to write down DeWitt equation for this Lagrangian which is basically the functional field derivative of the effective action, from which we can generate the Schwinger-Dyson equations, and an infinite tower of equations relating the correlation functions, i.e. the 2 point correlation function with the three point, and hence forth. Our current goal is to write the DeWitt equation for the case and show that it is well defined, meaning it is free from ultraviolet divergences. This happens because in our theory we have same number of fermions and bosons, and their divergences occur with opposite signs, thus they cancel each other. As in all SuperSymmetric theories, there are cancellation of these divergences, some complete and some incomplete, luckily in our case it is complete. In this context we also look at the much simpler model of N=1 Wess Zumino model in 2 dimensions, to understand the cancellation of bosonic and fermionic divergences in this case. Form these correlation functions we intend to do non-perturbative calculations for our theory in the future.

Why I recommend this Program

I recommend this program because it gives us a great working atmosphere. The institutes which are in the consortium are really well renowned and one can easily collaborate with many good people here. It also provides an oppurtunity for such an informal interaction with everybody, which is really nice. The half yearly workshops are also unique in a sense all the students meet up and discuss their work and listen to latest breakthroughs in the field of astrophysics, which is really motivating.

Philipp FLEIG (German)

Supervisor: Prof. H. Nicolai

Albert-Einstein-Institute

Research Activities

The title of my thesis is "**Quantum Gravity and Automorphic Functions**". Today, the two great pillars on which our modern understanding of physics rests are the theory of General Relativity on the one hand and Quantum Theory on the other hand. The further is a theory which describes phenomena happening on a very large scale, e.g. the scale of our Galaxy, and the latter is a theory describing things on a very small scale, e.g. the structure of atoms. Both theories have had remarkable success in their respective range of validity and have been proven experimentally up to very high accuracies. However there seem to be certain physical situations, e.g. Black Holes or the Big Bang, in our universe where one cannot just use one of the two theories to describe the physics that is happening, but one has to use a different kind of theory, which incorporates both, General Relativity and Quantum Theory at the same time. This theory generally goes by the suggestive name "Quantum Gravity". There are currently several different views on what the theory of Quantum Gravity should be and no clear picture has yet emerged. One version of Quantum Gravity, which is being discussed goes by the name "Arithmetic Quantum Gravity". It is a rather young theory and has mainly been developed within the last 10 years. In this theory a central idea is that the behaviour of a point in space-time (the space that we live in) can be described as if it was a small ball moving on a billiard table. The precise shape of the billiard table determines how exactly the ball moves and therefore determines the dynamics of space-time.

In a recent publication, done in collaboration with H. Nicolai and M. Köhn, we have managed to give a complete, geometric description of the billiard table mentioned above, as well as to calculate its volume. My current work is concerned with the symmetries, which arise in Arithmetic Quantum Gravity. I am working on this in collaboration with H. Nicolai and V. Belinski.

Why I recommend this Program

The field of relativistic Astrophysics has become an extremely diverse field, which in itself contains a wealth of different areas that one can work on and think about. Due to their complexity each area in itself has become highly specialized. The IRAP PhD program puts together people from the various areas of relativistic Astrophysics and gets them to talk to each other, always with the goal in mind that learning from each other is the best and fastest way of making progress.

Despite from learning a whole lot of new physics, this also teaches one how to communicate and explain ideas to people with a different background in physics.

Since the program includes people with different nationalities from all over the world, it is also a great opportunity for cross-cultural exchange, which is a lot of fun.

Bernardo FRAGA (Brazilian)

Supervisor: Prof. R. Ruffini

University of Roma

Research Activities

The title of my thesis is " **Cosmology and Galaxy Formation**". The classic work of Prof. Ruffini works over a wide range of subjects, one of which is the Theory of Dark Matter. Since the beginning of the 1930s, there were already observations that reported a disagreement between the total mass of galaxies and clusters of galaxies as measured by the rotation of such, and the mass inferred from the luminosity. This implied that there was some "missing" mass that do not emit light but interacts gravitationally. This remained somewhat obscure until the 1970s, when after a long work on rotation curves of galaxies, it was agreed that this curves were incompatible with galaxies composed only by baryonic matter (luminous matter). At first, it was believed that the dark matter was present on individual galaxies as a halo, with baryonic matter on the center. However, recent observations suggest that this is not right, and there may be a substantial amount of dark matter also in the center of the galaxies and in the galactic plane. Due to the fact that the dark matter does not emit light, its nature is so far not understood and we do not know which particle it is. There are different density profiles obtained with simulations and observations, and no model as of today can account fully for the different features of dark matter in different objects (individual galaxies, clusters and dwarf galaxies). We are working on a model of dark matter composed by fermions, particles with half-integer spin (like the proton, neutron), with no charge and a mass on the keV range, as proposed by Prof. Ruffini and others in 1990. This model could explain the halos of dark matter, but also is a potential explanation for what lies in the center of the galaxies, since the strongest candidate is a black hole, which could not explain some recent observations of the galactic center.

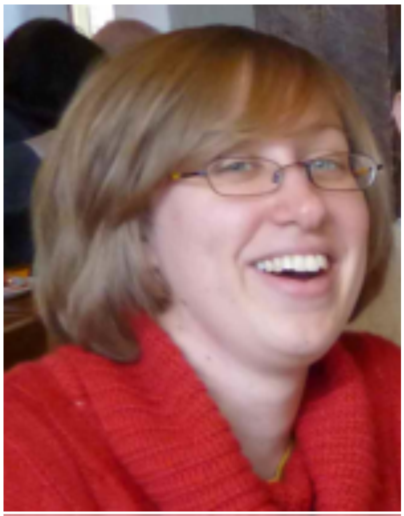
Why I recommend this Program

Cooperation is one of the keys to scientific progress, and in this program we have the possibility to be in contact with different researchers in different areas of astrophysics, thus not only working on our field, but also seeing how our work can affect other areas of astrophysics. This helps greatly in understanding astrophysics as a whole, and not be confined to our areas of research.

Christine GRUBER (Austrian)

Supervisor: Prof. H. Kleinert

Free University of Berlin



Research Activities

With my supervisor Prof. Kleinert it is possible to choose my research projects from a wide range of topics, stretching from gravity and general relativity to quantum field theory. At the beginning of my PhD, I was looking into the subject of BKL (Belinski-Khalatnikov-Lifshitz) cosmology, a rather mathematical branch of cosmology dealing with the treatment of singularities in the framework of general relativity. Singularities are points in spacetime with extreme conditions, where the density and other physical quantities diverge, as for example in black holes. In the vicinity of these singularities, the evolution of spacetime is governed by a set of differential equations, which lead to chaotic behaviour. BKL cosmology makes it possible by introducing certain approximations to describe the chaotic evolution qualitatively. I developed a numerical way to solve the governing equations to also have a quantitative description of spacetime around singularities.

Recently I have also been dealing with the opposite side of the spectrum of research possibilities – namely high energy particle physics, and the electroweak symmetry breaking. At high energies, as for example inside a very massive neutron stars or during the collapse of a massive object, the electroweak symmetry could be restored, which would lead to a very high pressure of the neutrinos present. This could lead to a huge explosion, which should be visible and detectable in the sky. In the context of this research, I have also studied electron-positron pair creation in different environments.

Why I recommend this Program

I think one very essential aspect of science is networking – to know what's being done in a field, to connect with other groups and to collaborate. And this is what the program is offering – there is a faculty of people working in all kinds of topics of Cosmology and Astrophysics, from which the students can choose, we can benefit from many meetings and schools and have opportunities to be trained in a broad range of subjects and collaborate with people within the network. It's important, besides studying intensely the own subject, also to have a broad overview of the general field, and the program supports both of those claims.

Vincenzo LICCARDO (Italian)

Supervisor: Prof. F. Frontera

University of Ferrara

Research Activities

The title of my thesis is "**Gama-ray lens development and test**". The main goal of the thesis concerns the development and test of a broad band (70/100 -600 keV) Laue Lens prototype for opening a new window for the deep exploration of the Galactic and extragalactic sky. No focusing instruments in this band are available till now. It is the first time that the development of a Laue lens for astrophysics is faced with a great effort. To this end, the doctoral student is being involved in a large national project, LAUE, scientifically led by the High Energy Astrophysics (HEA) group(PI: the doctoral candidate supervisor) of the Physics department of the University of Ferrara. The project is supported by the Italian Space Agency. The project is now in the design phase and is fully consistent with the timeline of the thesis preparation. The lens is based on the use of mosaic/curved crystals, that are being developed for this project, while the technology for properly positioning the crystals in the lens is the result of the experience gained with another project now concluded. The student will face several issues related to the LAUE project: the choice of the best crystals to be used for the lens, the data analysis of the imager/spectrometer data in the focal plane of the lens for establishing the best orientation of the crystals in the lens, the correction of the systematic errors, like the effect of the gamma-ray beam divergence, the measurement of the built lens petal optical properties and so on.The doctoral candidate will be part of a larger team, making possible a strict direct supervision. Results, also at intermediate level, will be presented in international conferences, like SPIE Symposia.

Why I recommend this Program

I think that the main difference between our program and the normal PhDs is the opportunity to travel, hence broad your mind, and to attend many meetings in which you have the possibility to know other scientists of the field who work in cosmology, general relativity, quantum field theory, and confronting your ideas with them. The schools in Nice are given by some of the leading experts on all the topics of the relativistic astrophysics, both experimental and theoretical.
Moreover, you have the opportunity to meet the other students of the program, and be part of a group, so that you may have a general overview of all fields involved in the network, trying to find a link between different topics which could lead to a common goal.
Finally, the Erasmus Mundus Program provides you a complete education in the high energy astrophysics and an important experience on the international relationship, essential for your future career.

Sheyse MARTINS (Brazilian)

Supervisor: Prof. R. Ruffini

University of Roma

Research Activities

The title of my thesis is " **Electrodynamics of Neutrons Stars**". The classic work of Oppenheimer and Volkoff (1939) addresses the problem of the construction of configurations of equilibrium of neutron stars composed only by neutrons, within the Einstein theory of relativity. For the more general case when protons and electrons are also present in neutron star interiors, in nearly all of the scientific literature it is assumed that the condition of local charge neutrality applies inside the neutron star, namely, no electromagnetic interactions between protons and electrons are considered at all. Consequently, the corresponding solutions of the Einstein equations for a non-rotating neutron star, following the work of Tolman (1939) and of Oppenheimer and Volkoff (1939), have been systematically adopted.

In our research work we prove that this approach is conceptually inconsistent as soon as a self-gravitating system of neutrons, protons and electrons is considered. Therefore, we work on a self-consistent theory of neutron stars in the framework of general relativity, including all the interactions between particles with particular emphasis on the electromagnetic interactions between protons and electrons. The analysis of the properties of the new neutron star equilibrium configurations and their consequence on the process of gravitational collapse to a black hole is one the main goals of our research project.

The observation of the late X-ray emission of the Gamma-Ray Bursts (GRBs) associated to Supernova explosions within the so-called GRB-Supernova connection problem has evidenced the possibility of witnessing the thermal evolution of neo-neutron stars: neutron stars just formed in the Supernova event with expected very large temperatures of tens of billion degrees. Therefore, we are exploring the effects of very large temperatures on the equation of state of nuclear matter at high densities important for neutron stars as well as on the different emission mechanisms leading to the cooling of such newly-born neutron stars.

Why I recommend this Program

I think the most important aspect of IRAP PhD is the opportunity to interact with teachers and students of all different themes of astrophysics and the participation in schools and meetings. Be present where discuss the new physics and all that scientific exchange, are essential for study and understanding of our topics and our research, as well as astrophysics in general.

Ana PENACCHIONI (Argentinian)

Supervisor: Prof. R. Ruffini

University of Roma

Research Activities

The title of my thesis is "**Multiwavelength analysis of Gamma Ray Bursts emission**". My thesis work is based mainly on the study of GRBs. I work both on the experimental and theoretical aspects. I am learning to reduce the data of many satellites like Fermi, Swift and BATSE, and then build their light curves and spectra through specific tools and codes. Then, by means of theoretical models and applying all the knowledge of physics I have, I try to explain the observed behavior and arrive to any conclusion. There are currently many models which are the leading ones and most of the scientists use for their research work, but at the same time there are many controversies about which is the one to use. The main objective of my work is to reach their complete understanding so that I can make my own way through this field, taking the best part of each one and merging them in a single improved approach.

Why I recommend this Program

There is a very important feature of this PhD program, and is the fact that you are continuously traveling all around the world. This way you meet important scientists and have the opportunity to interact with them, not only to exchange your opinion but also to learn from them all the small but fundamental things that make you grow as a scientist. By the way, you start to become known in the scientific community from the very beginning, which represents a great advantage over the other programs.

Vineeth VALSAN (Indian)

Supervisor: Prof. F. Frontera

University of Ferrara

Research Activities

The title of my thesis is "**Laue lens configuration studies for highly sensitive broad band X-/Gamma-ray astronomy missions**". The main goal of the thesis is the study of a broad band (1-600 keV) multi-optics focusing telescope configuration for unprecedented observations of Galactic and extragalactic objects. While at energies below 70/100 keV, the technology for building focusing optics (based on multilayers) is already mature, focusing optics at higher energies are still lacking. Motivated by the astrophysical importance of extending the focusing band up to 600 keV, with the support of the Italian Space Agency, the development of a broad band (70/100 -600 keV) Laue Lens is being performed in Italy, under the scientific PI-ship of Filippo Frontera, at the Physics Department of the University of Ferrara. I am involved in this project, with the goal of developing a code that simulates a Laue lens made of mosaic curved crystals, like that foreseen to be developed. With this code we can, first, establish the best crystal and lens parameters of the lens prototype we want to build, later, we can compare the experimental results of the developed prototype with expectations.

At first, I made a study of X-/gamma-ray detectors and their theoretical principles. After having made measurements in the LARIX laboratory, I started with simulations and modelling of different parameters and functions that are necessary to get the best results practically for a Laue lens made of different types of crystals.I also modelled the basic petal structure of the proposed Laue project, with single material crystals. The minimum and maximum energy that this structure will provide with these cystals was also modelled.

Why I recommend this Program

Through this program we have the unprecedented opportunity to meet and interact with one of the pioneer group of high energy astrophysics. This is a very good platform to gain knowledge in the related areas also. The Instrumentation aspects of high energy astrophysics in University of Ferrara is one among the best in this area. It is the first time that the development of a Laue lens for astrophysics is faced with a great effort.