Enclosure 10

ICRANet ICRA

on the occasion of the

14th Marcel Grossmann Meeting – MGXIV

in celebration of

the International Year of Light 2015
the 100th anniversary of the Einstein's equations
the golden jubilee of Relativistic Astrophysics

In support of

United Nations
Educational, Scientific and
Cultural Organization

International
Year of Light
2015

The ICRANet Seats

ICRANet Headquarters in Pescara (Italy).

ICRANet seat in Nice (France).

The University of Rome "La Sapienza" where the Physics Department hosts the ICRANet seat in Rome (Italy).

National Academy of Sciences of Armenia, which hosts the ICRANet seat in Yerevan (Armenia).

(Above:) CBPF, which hosts the ICRANet seat in Rio de Janeiro. (Below:) The planned seat at Cassino da Urca (Brazil).

This brochure reviews some background facts concerning the founding of ICRANet and its current structures and then turns to the 2015 celebrations of the Year of Light and the ICRANet initiated International Relativistic Astrophysics Ph.D. program (the IRAP-PhD). It then addresses the birth of relativistic astrophysics following the first fifty years of the existence of general relativity plagued mainly by the absence of observational or experimental activity.
Four events marked the onset of relativistic astrophysics: the discovery by Schmidt of the first quasar in 1962, of Scorpius X1 by Riccardo Giacconi in 1963, of the cosmic background radiation by Penzias and Wilson in 1964, and of pulsars by Jocelyn-Bell and Antony Hewish in 1967. These events led to a systematic development of the understanding of the four pillars of relativistic astrophysics: supernovae where observations of the CRAB Nebula are still relevant today, white dwarfs and neutron stars, black holes and their first identification in Nature in Cygnus X1 found by Riccardo Giacconi with the UHURU satellite based on the conceptual background developed by our group in Princeton, and finally the discovery of gamma ray bursts as the largest energy source delivered in the shortest time of any astrophysical phenomenon. ICRA and ICRANet were established as institutions dedicated to an in-depth analysis of these topics. The rise of the new physics and astrophysics surrounding these four fundamental pillars is then described, arriving at the present frontier and ICRANet's unique role in joining them together in a single cosmic matrix involving induced gravitational collapse and black hole formation occurring in a many body interaction lasting less than three minutes in our observations from the Earth and made visible all over the Universe by the energy of 10^{54} erg equivalent to the luminosity of all the stars of the Universe emitted in that brief event. We review as well ongoing activities in the various ICRANet Centers.

1.1 ICRANet and its members

(from the Preamble published in the Official Gazette No. 53 of March 5, 2005, Law 10 February 2005, No. 31, approved by the Chamber of Deputies and the Senate unanimously)

> *"Aware of the importance of research in relativistic astrophysics for the understanding of life and the evolution of stars and the structure of our universe as well as for the identification of the fundamental laws of nature;*
> *Aware that research in this field is necessarily based on international cooperation;*
> *Recognizing that the study of celestial and astrophysical objects has deep roots in many cultures;*
> *Considering the great popular interest in all countries for the discovery of celestial objects such as pulsars, quasars, black holes;*
> *Stressing the importance for the development of many technologies and techniques used in and related to research in relativistic astrophysics such as optical technologies, radio, space and telecommunications;*
> *Given that the parties to this Agreement wish to establish an International Network of Centers for Relativistic Astrophysics, hereafter referred to as ICRANET as an independent international organization, with its own management, with international status and powers, privileges, appropriate immunity, as well as other conditions necessary for its effective operation, so that it can achieve its objectives;*
> *Considering that the Italian government is willing to start negotiating a Headquarters Agreement for ICRANET;*
> *The signatory parties have agreed...".*

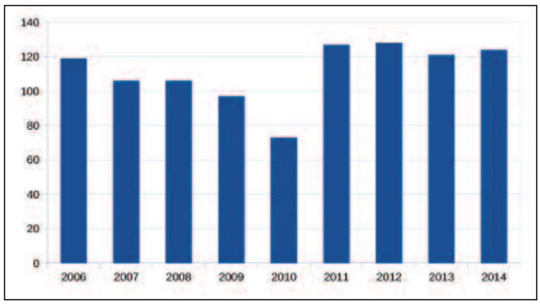
The founding members of ICRANet are Italy, Custodian of the Agreement, Armenia, the State of Vatican City, Stanford University, the University of Arizona in Tucson, ICRA. On August 12, 2011 the Federative Republic of Brazil was made a member by a unanimous vote of the parliament House and Senate.

Seat agreements, establishing rights and privileges, including extraterritoriality, have been signed for the Seat in Pescara (ICRANet Headquarters), for the seat in Rio de Janeiro in Brazil and for the Seat in Yerevan in Armenia. Activities in different locations are made possible by the international research optical fiber network from Italy to Armenia, Switzerland, France, the US and Brazil.

The international high speed fiber optics network which connects the ICRANet Headquarters to the seats in Nice, Rio de Janeiro, Rome, Stanford, Tucson, and Yerevan, passing through Geneva and Fermilab in Chicago. In the box, the Undersecretary Mario Giro and the Prefect of Pescara Vincenzo D'Antuono attend the opening ceremony of the optical fiber connection of the ICRANet Headquarters in Pescara January 21, 2014.

Prof. Remo Ruffini is the Director of ICRANet which has a Steering Committee and a Scientific Committee consisting of representatives of the countries and Member Institutions. The first President of the Scientific Committee was Prof. Riccardo Giacconi, recipient of the 2002 Nobel Prize for physics, who ended his term in 2013 for reasons of age. The Faculty consists of Professors Vladimir Belinski, Carlo Luciano Bianco, Luca Izzo, Jorge Rueda, Remo Ruffini, Gregory Vereshchagin, and She-Sheng Xue, and is supported by an Adjunct Faculty made up of more than 30 internationally renowned scientists participating in ICRANet activities, and between eighty "Lecturers" and "Visiting Professors". Among these, besides the aforementioned Nobel Prize Riccardo Giacconi, are the Nobel Laureates Murray Gell-Mann, Theodor Hänsch, Gerard 't Hooft and Steven Weinberg. The complete list of all the names is online at the website http://www.icranet.org/.

Between 2006 and early 2015, ICRANet has produced 1,800 scientific publications in its various lines of research.



Number of scientific publications of ICRANet for each year from 2006 to 2014.

1.2 The ICRANet celebrations of 2015, the *International Year of Light*.

2015 celebrates the initiative of the United Nations and UNESCO as the "*Year of Light*", the

Albert Einstein and Tullio Levi Civita

Group picture at MG1 Meeting in Trieste.

Poster of MGXIV.

centenary of the formulation of the equations of general relativity by Albert Einstein, and the fiftieth anniversary of the birth of relativistic astrophysics. ICRANet is a participating member of these celebrations. Writing down the equations of general relativity was no doubt the result of Einstein's brilliant physical intuition, based from the mathematical point of view on the work of Gregorio Ricci Curbastro and Tullio Levi Civita of the University of Padua and the University of Rome "La Sapienza". This combination, so unique in the history of physics and mathematics, has produced probably the highest expression of the thought of Homo-Sapiens. Essential to this work was the intervention of Marcel Grossmann of the University of Zurich who was close to Einstein and who had a deep knowledge of the Italian school of geometry. In order to promote this important collaboration between physics and mathematics, in celebration of that historic event, Remo Ruffini and Abdus Salam established in 1975 the Marcel Grossmann (MG) Meetings which take place every three years in different countries. MG1 and MG2 were held in 1975 and in 1979 in Trieste; MG3 in 1982 in Shanghai; MG4 in 1985 in Rome; MG5 in 1988 in Perth; MG6 in 1991 in Kyoto; MG7 in 1994 at Stan-

Public lecture by Prof. Remo Ruffini in João Pessoa, in the framework of the Second ICRANet César Lattes Meeting, a satellite meeting of MGXIV.

Prof. Remo Ruffini presents C.N. Yang with the Marcel Grossman Award during the Fourth Galileo-Xu Guangqi Meeting, a satellite meeting of MGXIV.

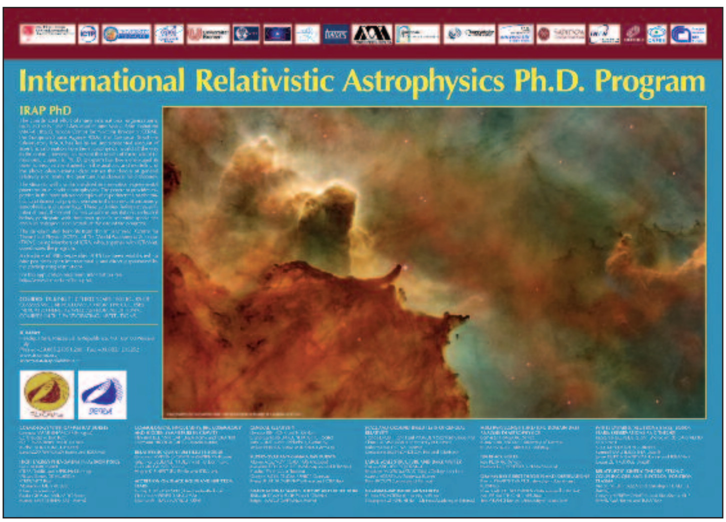
The Marcel Grossmann Meeting logo is traditionally the ICRANet logo with the colors of the host city or country.

ford; MG8 in 1997 in Jerusalem; MG9 in 2000 in Rome; MG10 in 2003 in Rio de Janeiro; MG11 in 2006 in Berlin; MG12 in 2009 in Paris; MG13 in 2012 in Stockholm.

The Fourteenth MG Meeting (MGXIV) takes place in Rome July 12-18, 2015 as part of the celebration of the "Year of Light". Scientists from over 50 countries will be present. During the course of this MGXIV meeting, the Marcel Grossmann Award will be presented both to scientists and institutions that have distinguished themselves for their fundamental contributions to relativistic astrophysics. Among them: T.D. Lee., K. Nomoto, M. Rees, Y. Sinai, S. Tsuruta, C.N. Yang, and the Director General of the European Space Agency (ESA) J.D. Woerner. For the first time MGXIV is accompanied by satellite meetings in Brazil (April 13-18 in Rio de Janeiro), China (May 4-8 in Beijing), in France and the Principality of Monaco (September 14-26), in Colombia (November 27-30), and Mexico (December 1-5).

1.3 ICRANet and the International Relativistic Astrophysics PhD (IRAP-PhD).

Since 2005 ICRANet co-organizes an International Ph.D. program in Relativistic Astrophysics (International Relativistic Astrophysics Ph.D. Program, IRAP-PhD), together with: AEI - Albert Einstein Institute - Potsdam (Germany), CBPF - Brazilian Center for Physics Research (Brazil), Indian Center for Space Physics (India), INPE (Instituto Nacional de Pesquisas Espaciais, Brazil), Institut Hautes Etudes Scientifiques - IHES (France), Observatory of the Côte d'Azur (France), Observatory of Shanghai (China) Observatory of Tartu (Estonia), University of Bremen (Germany), University of Oldenburg (Germany), University of Ferrara (Italy), University of Nice (France), University of Rome "La Sapienza" (Italy), and the University of Savoy (France). The IRAP PhD program grants the first joint Ph.D. degree among the participating institutions, and has been a part of the prestigious Erasmus Mundus program of the European Commission. Par-



IRAP-PhD Poster 2015-2016.

ticular attention is going to be devoted in the forthcoming years, within the IRAP PhD program, to Universities of Latin America who have signed a collaboration agreement with ICRANet.

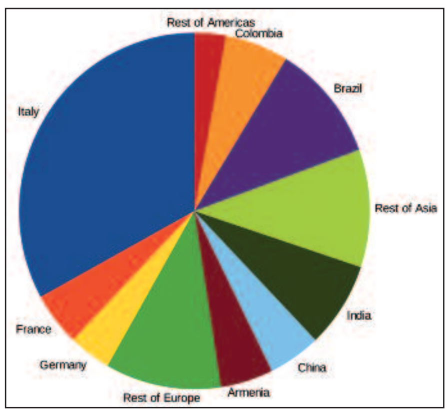
In the next decade the international scientific community is engaged in a series of large astronomical projects like the construction of the largest optical telescope in the world, the E-ELT (European Extremely Large Telescope), with a primary mirror of 42 meters, which will be built by the European Southern Observatory in the Atacama Desert in Chile; the construction of SKA (Square Kilometer Array), the largest radio telescope in the world located partly in Australia and in South Africa, and the CTA (Cherenkov Telescope Array), which will study high energy astrophysical phenomena from the ground. The IRAP-PhD program developed by ICRANet aims to create the conditions for the formation of a new generation of scientists, leaders in their respective fields of astrophysics, and who will be the users of these instruments on which construction has begun. For this reason, we have created a network of universities and research centers that can offer highly complementary skills. Every student admitted to the IRAP-PhD is part of a team in one of the laboratories of the consortium, and each year visits the other centers to keep track of the latest developments with the leading experts in the world in general relativity, relativistic astrophysics, cosmology and quantum field theory.

Among the associated centers, besides those engaged in theory, there are those performing experiments and observations. In this way the Ph.D. students can have a complete formation of theoretical relativistic astrophysics, and a vision of how to complete a specific space mission or land based observation campaign in astrophysics.

All institutions involved in the IRAP-PhD have extensive experience in international collaborations, both at the level of professors as well as that of researchers, post-doctoral students and PhDs.

The official language of the program is clearly English, but students have the opportunity to learn the language of their host country, following a variety of courses at the partner universities.

To date, the IRAP-PhD has seen the enrollment of 103 students: 1 from Albania, 2 from Argentina, 5 from Armenia, 1 from Austria, 2 from Belarus, 11 from Brazil, 5 from China, 6 from Colombia, 1 from Croatia, 5 from France, 4 from Germany, 8 from India, 4 from Iran, 34 from Italy, 2 from Kazakhstan, 1 from Mexico,



Geographical distribution of IRAP-PhD students.

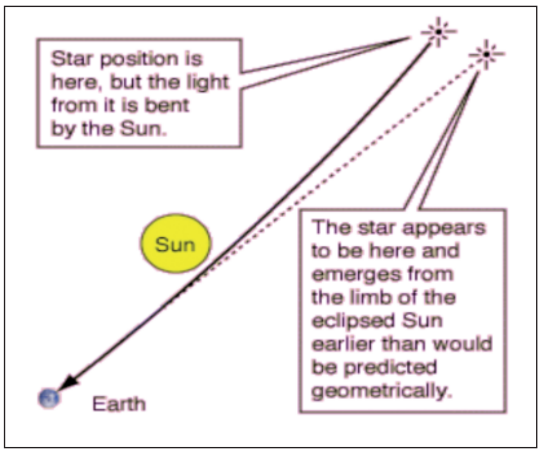
1 from Pakistan, 3 from Russia, 1 from Serbia , 1 from Sweden, 1 from Switzerland, 1 from Taiwan, 2 from Turkey, 1 from Ukraine.

1.4. Admission of New Members to ICRANet

In order to foster activities in relativistic astrophysics, new countries or institutions are certainly welcome to join ICRANet. This will create, in the context of this network, mobility and centers of research linked electronically, as well as a welcome enlargement of both the ICRANet Steering Committee and the ICRANet Scientific Committee. Each center of this network should have a staff of no more than 100 people, including both scientists and administrators. If there is a need to increase this number, a new and separate center should be opened. Funding will come through a law of the host country and each seat will have immunities and privileges for itself and its staff, as well as extraterritoriality (see ICRANet Statute at: http://www.icranet.org/agreement_statute.pdf). Each new member will clearly enjoy the benefits of all the ICRANet facilities, e.g. access to the data centers, as well as participation in the organization of its sponsored schools and meetings like the Marcel Grossmann Meetings.

2 From astrophysics to relativistic astrophysics in the last 50 years.

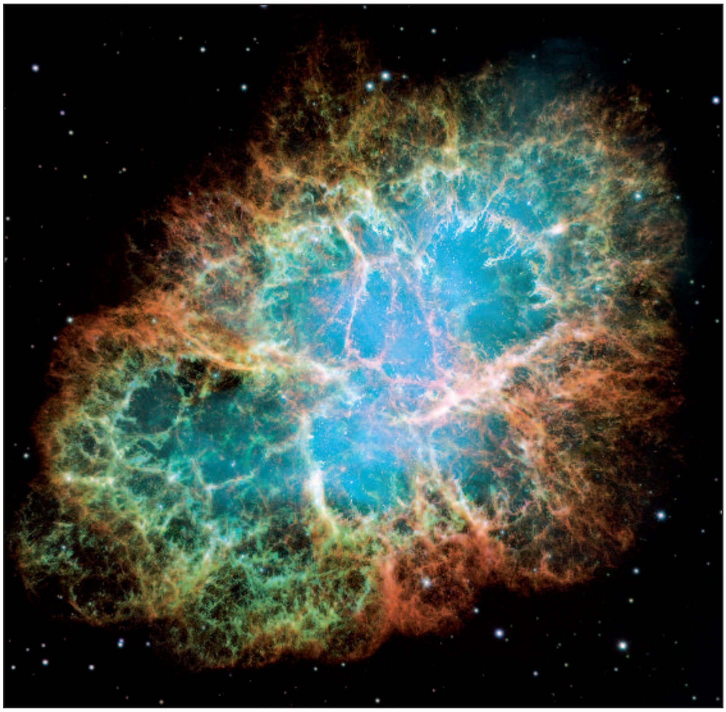
As recalled in the forthcoming book (R. Ruffini, "Einstein, Fermi, Heisenberg and Relativistic Astrophysics: Personal Reflections", World Scientific, "EFH" hereafter), the first 50 years of the theory of general relativity had a particularly difficult start. On the one hand, the theory presented mathematical difficulties never encountered before. One had to deal with a system of 10 partial differential equations in four variables, which were practically insoluble except in extremely idealized and particularly simple cases. From the experimental and observational standpoint, phenomena within our solar system where the effects of general relativity could be detected consisted of perturbative effects so quantitatively small that, in view of the theoretical difficulties, hardly motivated a substantial scientific effort. These effects are, as is well known, the anomalous precession of the perihelion of Mercury, the deflection of light from distant stars in the passage near the Sun's limb observed for the first time in Sobral, Brazil on May 29, 1919, and finally the red shift of spectral lines.



In its first 50 years general relativity aroused the interest of only a small number of mathematicians interested in the technical aspects of the field equations, and had moved more and more away both from the world of physics as well as from that of astronomy. There remained only a very small number of highly skilled theoretical physicists fascinated by this theory who appreciated both the conceptual depth as well as its formal elegance. Among these were Enrico Fermi, Lev Davidovič Landau and Evgenii Mikhailovich Lifshitz, and Wolfgang Pauli.

2.1 What are supernovae.

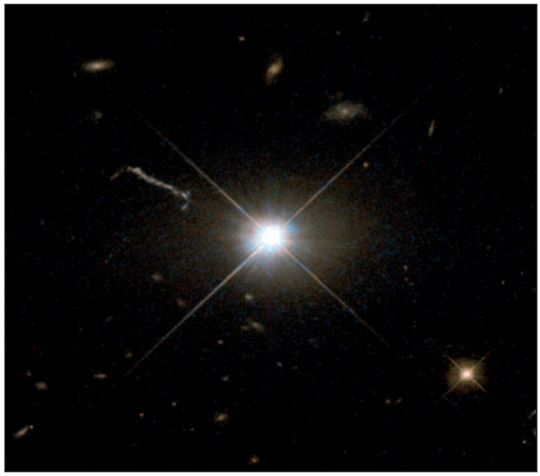
The early premonitory signs of a new era came from California. There a new class of powerful optical telescopes funded mainly by private donations allowed us to look beyond our planetary system and for the first time to push ourselves outside of our own galaxy. Thus in 1929 the first evidence of the recession of galaxies was observed by Edwin Hubble with the Hooker telescope at the Mount Wilson Observatory in California and was reported by Hermann Weyl and Alexander Friedman in Leningrad as the first evidence of the dynamic expansion of our universe, explained precisely by a solution of Einstein's equations of general relativity. It was again the Mount Wilson Observatory which allowed a renewed focus by Walter Baade and Fritz Zwicky on the Crab Nebula, the remains of the supernova in the year 1054 and observed at the time by Chinese, Korean and Japanese scientists. Baade and Zwicky proposed that the activity of these supernovae gave rise to cosmic rays, which today we understand play a key role in biological evolution on Earth, and that even the most precious materials that are found on the surface of planet Earth, such as gold, were formed thanks to thermonuclear processes that occur during the explosion of a supernova.



The "Crab Nebula" observed by the Hubble Space Telescope.
Credit: NASA, ESA, J.Hester and A.Loll (Arizona State University)

2.2 What are white dwarfs, neutron stars, pulsars.

Into this reality entered some new conceptual ideas put forth by Ralph Howard Fowler, Edmund Clifton Stoner, Subrahmanyan Chandrasekhar, George Gamow, Enrico Fermi and Robert Oppenheimer. Chandra gave an explanation, awaited for many years, of the so called "white dwarf stars" that he proved are kept in equilibrium by an electron gas described by Fermi-Dirac quantum statistics. For the first time, since a white dwarf has a mass of about one solar mass and a radius similar to the Earth's, there was some evidence for an astrophysical object with a density one hundred thousand times greater than that observed in the Solar System. Soon it was George Gamow who generalized this same idea and showed that stars which are more dense, formed mainly of neutrons, should exist with a solar mass but a diameter of only 10 kilometers. Again the balance was ensured by the fact that the neutrons, like the electrons considered by Chandrasekhar, are "fermions", and it is precisely Fermi-Dirac statistics which guarantees the equilibrium of these self-gravitating systems. As a consequence, these "neutron stars" had to have a density ten thousand billion times greater than those observed in the Solar System. It was Oppenheimer and his school, Robert Serber and George Volkoff, who completed this analysis in the context of general relativity. It was again Oppenheimer, with his other student Sneider, who hypothesized that at the end of the evolution of a sufficiently massive star, gravitational collapse could bring the star to a critical radius completely dominated by general relativity.



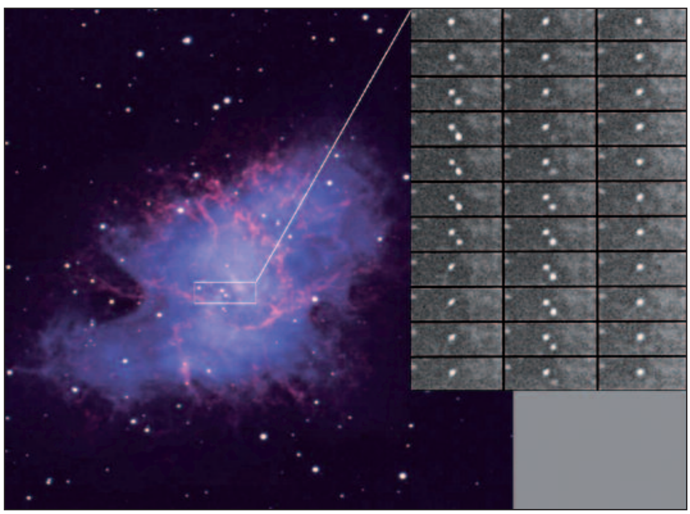
The Quasar 3C273. Credit: Hubble Space Telescope

This conceptual expansion of knowledge was followed by a second wave of four discoveries in the observational domain that came to mark a historic moment:

1) It was exactly the evolution of large telescopes in California, with the construction of the 5-meter Hale telescope on Mount Palomar, that led Maarten Schmidt in 1962 to the discovery of the farthest known object in the universe (at a cosmological redshift z = 0.158, amounting to 2.4 billion light years), with a brightness of 10^{48} erg/s, equal to that of a million billion stars like our Sun, the "quasar 3C273." Suddenly we realized that there were systems in our universe where general relativity could play a key role. The scientific community met in Dallas, Texas, in the first international meeting held in relativistic astrophysics: the First Texas Symposium on Relativistic Astrophysics.

2) After a few months, in 1963, using for the first time the technologies developed for the diagnostics of nuclear explosions after the end of World War II, Riccardo Giacconi sent an X-ray detector above the Earth's atmosphere to avoid absorption and discovered the first cosmic X-ray source in our galaxy, in the constellation Scorpion, named Sco-X1, which would soon be identified by Iosif Shklovsky as a possible binary system containing a neutron star.

3) In 1964 the conceptual picture developed by George Gamow and Enrico Fermi of an initially hot universe was definitively confirmed by the observation of millimeter radio waves by Arno Penzias and Robert Wilson. At this point the stage was set to begin the age of relativistic astrophysics, both from the observational as well as the conceptual point of view, fully relying on Einstein's theory of general relativity.



The pulsar in the Crab Nebula. Credit: N.A.Sharp/NOAO/AURA/NSF

4) The real start date was November 28, 1967: on the basis of radio technology developed in World War II for radar, the radio astronomy school in England discov-

ered pulsars, thanks to Jocelyn Bell, and soon after, a particular pulsar with a period of 33 ms was identified to the right of center in the Crab Nebula. This finally showed that after years of conceptual and technological developments, in fact neutron stars did exist, and it was confirmed not only by the very short rotation period, but also by the lengthening of this period in time, what is technically called the first derivative of the period, which amounted to 12.5 ms/year, showing that the energy source of this star, as indicated by Arrigo Finzi, is the rotational energy of a neutron star, which generates the energy needed for the illumination of the "Crab Nebula".

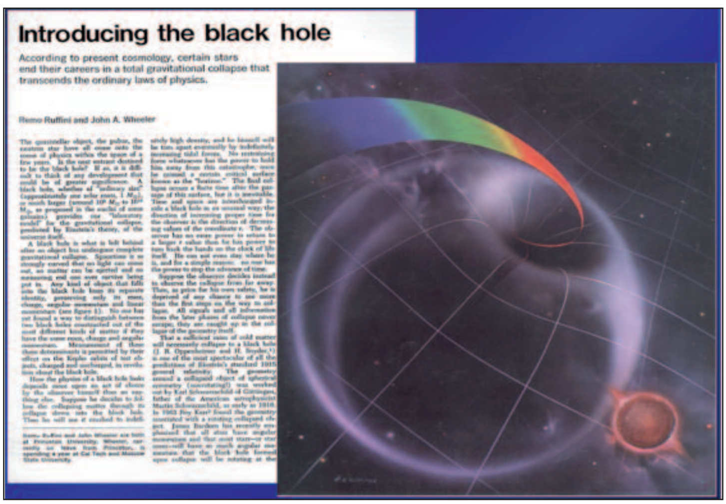
2.3 What are black holes.

Now the discoveries followed one after another. The interactions between the theory and experiment, which first occurred over time scales of decades, occurred on time scales of years, months, and gradually ever shorter, to days and hours. Three research theoretical groups played a key role during this period: the one in Princeton led by John Archibald Wheeler that Remo Ruffini joined in 1968 – this is the group that directly reinvigorated the message of Albert Einstein; the Moscow group led by Jakov Borisovič Zel'dovič, father of the Soviet H-bomb together with Andrej Dmitrievič Sakharov, surrounded by a group of young researchers that included Rashid Sunyaev; and a group of young researchers in Cambridge, England, almost all born in 1942, including Martin Rees, Stephen Hawking, Brandon Carter and George Ellis.

Einstein, Yukawa, Wheeler

It was in this period that Wheeler with Remo Ruffini launched the challenge: not to stop at the study of neutron stars, but to go beyond with the introduction of the then only conceptual black holes as new astrophysical objects.

It was precisely at Princeton University, where 2% of the physics students obtained the Nobel Prize, that a limited number of enthusiastic students worked with Ruffini and Wheeler in close contact with the data from NASA space missions. The launch of the Uhuru satellite by Riccardo Giacconi and his group led to the identification of a large number of binary systems consisting of a neutron star and a star of tens of solar masses, like Cen-X3. The situation was ready for the most difficult step, to identify for the first time a black hole in our galaxy.



Introducing the black hole

According to present cosmology, certain stars end their careers in a total gravitational collapse that transcends the ordinary laws of physics.

Remo Ruffini and John A. Wheeler

Prof. Giacconi receives the Nobel Prize in Physics (2002).

The discovery was made by Riccardo Giacconi's group using Harvard University data from the UHURU satellite on Cyg-X1 in the constellation Cygnus, and the conceptual identification was made by Ruffini and his team at the Texas Symposium Meeting in New York, recognized by the Cressy Morrison Award given to Ruffini by the New York Academy of Science, and later by the Nobel Prize awarded to Riccardo Giacconi. In his acceptance speech for the Nobel Prize Giacconi states the crucial point: "*The estimated mass for the compact object was greater than six solar masses. Rhoades and Ruffini had shown in 1972 that black holes would have masses greater than 3.4 times the mass of the Sun*" (see also R. Giacconi, R. Ruffini, "Physics and astrophysics of neutron stars and black holes", Cambridge Scientific Publishers; 2nd Revised edition edition, 2009).

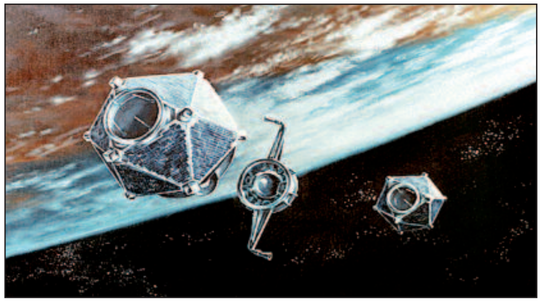
Prof. Ruffini receives the Cressy Morrison Award of the New York Academy of Sciences (1973).

In the meantime, Ruffini advised the Thesis of two Ph.D. students in Princeton: Demetrios Christodoulou, an extremely young student from Greece with unprecedented mathematical skills who was jointly advised by Ruffini and Wheeler, and Clifford Rhoades, a young military officer in the ROTC program who summed his orderliness to the rigor of computation. The Rhoads-Ruffini critical mass limit to neutron stars was so established, as well as the Christodoulou-Ruffini mass-energy formula of the black holes. Details of this exciting discovery moment are given in the above mentioned EFH book. From this mass-energy formula came a shocking new paradigm: a black hole, besides attracting and completely disappearing all the material in its immediate surroundings, can paradoxically be a tremendous source of energy because, unlike a star where only 1% of the mass can be transformed into energy during its lifetime of about 5 billion years, in the birth of a black hole up to 50% of its mass-energy should be extractable in the few milliseconds that characterize the gravitational collapse.

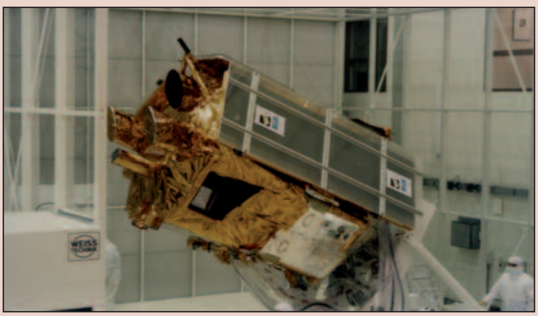
The identification of neutron stars in radio waves and black holes by X-ray astrophysics left open the observational verification of this shocking paradigm, namely that at the time of the formation of a black hole an amount of energy equivalent to a solar mass, or a thousand billion billion billion times that of a typical atomic bomb, could be emitted in a split second; in other words, a release of energy, in a second, equivalent to the energy radiated at that very second by one billion galaxies, each containing a trillion stars, in other words practically by all the stars of the universe. This prediction was inherent in the Christodoulou-Ruffini mass-energy formula.

2.4 What are gamma-ray bursts (GRBs).

Paradoxically, again the action of an astrophysicist, one who had angered the military and political classes, allowed a major step forward towards the discovery of such a process. Jakov Borisovič Zel'dovič had advanced a crazy idea: to demonstrate the superiority of the Soviet Union, both in the development of rockets and atomic weapons, by being the first to send a rocket to the Moon to explode an atomic bomb that would be announced at a particular time and visible to all the inhabitants of the Earth. This absurd idea was clearly rejected with disgust. There was also another point of physics to keep in mind: on the Earth, as was well known from nuclear bomb diagnostics, the explosion of an atomic bomb is connected to a spectacular X-ray emission and, in the absence of an atmosphere, a possible atomic explosion on the moon would appear only in gamma rays and would not have been a sufficiently "scenic relevance." In the Russian world, some argue today that Zel'dovič was in fact the one who had only demonstrated the infeasibility of the mission. But at this point excuses aren't needed: the military and politicians took this danger very seriously and in implementing the monitoring plan for the non-proliferation of nuclear weapons on Earth and in space, sponsored by the United States, put into orbit 6 pairs of omni-directional satellites called "Vela", which could detect X- and gamma ray signals from all of space outside the Earth's atmosphere, with atomic clocks of extremely high precision onboard. By triangulating the arrival time from at least 4 satellites it would be possible to identify any nuclear explosion



A pair of "Vela" satellites.
Credit: Los Alamos National Laboratory

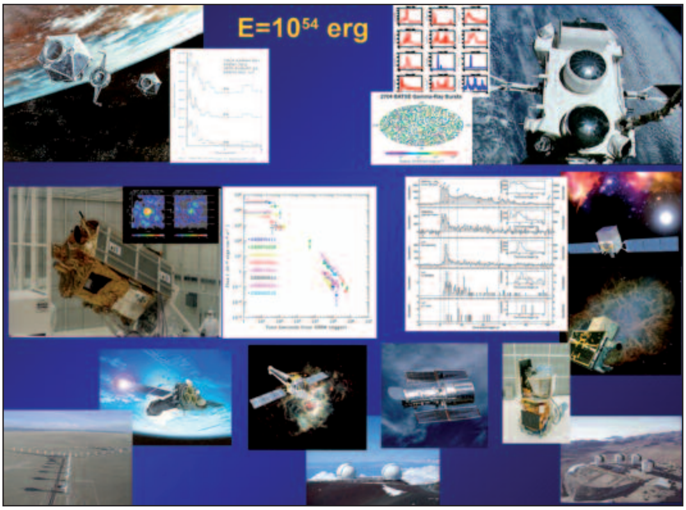


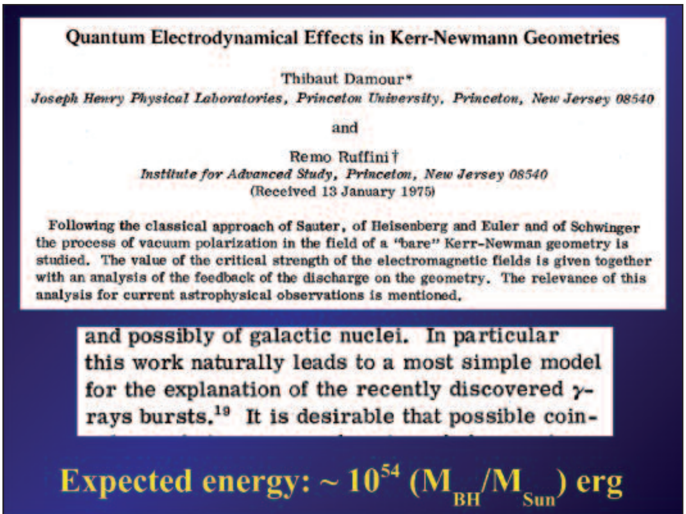
(Credit: Agenzia Spaziale Italiana (ASI) and the BeppoSAX SDC).

The project SAX was the first scientific satellite designed by the Italian Space Agency (ASI). Begun in the 1970s, it had many delays due to the many changes that also developed in designing a new mission not necessarily in the beaten track from the great Soviet and American space agencies. The idea was suggested by the presence in the project of a great astrophysicist, Giuseppe Occhialini and his collaborators. One should not forget that "Beppo" Occhialini, who had missed two Nobel Prizes in his youth, had also been the professor of Riccardo Giacconi in Milan. The originality of the mission consisted in uniting in a single satellite the tools of both the X-ray and gamma ray communities. The novelty and uncertainty of the mission had led to long delays. It was passed from one mission equally sharing costs between Italy and the Netherlands to a much more expensive mission with a fixed Dutch contribution. A moment of panic came to the Scientific Committee of ASI, when even the limited Dutch contribution, which was to provide the wide field (WFC) X-ray detectors, was missing. The Scientific Committee of ASI, in an act of courage, took charge. After the launch, three of the four gyroscopes failed. Nevertheless, the fortune, the courage, and will of a small number of young researchers trained in Italian universities led probably the most important astrophysics mission, which allowed the identification of the locations of GRBs and the determination of their cosmological distances. The economically serious delays, however, were paradoxically essential to its success, because even the Hubble Space Telescope, which was essential for the optical identification of GRBs, was launched nearly simultaneously with BeppoSAX.

both on Earth and on the Moon, and a priori, in all of space. The satellites were secret, and only later in 1974 were results, totally unexpected, made public and presented by Herb Gursky and Remo Ruffini at a conference of the AAAS in San Francisco (see H. Gursky, R. Ruffini, "Neutron stars, black holes and binary X-ry sources", D. Reidel Publishing Company, 1975). In fact during the years Vela was active it was possible to verify that every day something happened that was actually very similar to a nuclear explosion but it did not come either from the Earth or the Moon or from any of the planets of the Solar System. This was a deep mystery and increased by the fact that Vela, designed to test nuclear explosions on Earth or on the Moon, was not able to identify the sources of these extraterrestrial signals. Their angular resolution was thus limited to sources outside the Solar System where literally tens of billions of stars could be candidates to produce these signals and their identification was hopeless.

The mystery generated thousands of scientific papers, numbering well above the number of observed events. But in those same days, after the presentation at the conference, Ruffini with Thibault Damour, a collaborator from France with him both at Princeton and Stanford, suggested that the source of these events was precisely the birth of a black hole. They presented this work in the prestigious American journal Physical Review Letters. This es-




Quantum Electrodynamical Effects in Kerr-Newmann Geometries

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(Received 13 January 1975)

Following the classical approach of Sauter, of Heisenberg and Euler and of Schwinger the process of vacuum polarization in the field of a "bare" Kerr-Newman geometry is studied. The value of the critical strength of the electromagnetic fields is given together with an analysis of the feedback of the discharge on the geometry. The relevance of this analysis for current astrophysical observations is mentioned.

and possibly of galactic nuclei. In particular this work naturally leads to a most simple model for the explanation of the recently discovered γ-rays bursts.[19] It is desirable that possible coin-

(Above:) The paper by T. Damour and R. Ruffini, on Phys. Rev. Lett. 35 (1975) 463, with the prediction of the GRB energetics. (Below:) Jim Wilson, Francis Everitt, Remo Ruffini and Thibault Damour in 1975.

tablished the fact that if this model could be verified, then the energy of these events would necessarily have to be 10^{54} erg, i.e., as already stated, precisely equal to the energy emitted at the same time by all the stars in the universe combined. We were facing a new form of energy, different from traditional chemical or electromagnetic or nuclear energy: the "blackholic" energy! The race was on to verify this unsettling possibility that made general relativity the key to the most powerful explosions in the universe second only to the Big Bang, and it ended only in 1997 with the observations of the Italian-Dutch BeppoSAX satellite, which opened up a new era in relativistic astrophysics with a virtuoso collaboration between all the satellites operating outside the Earth's atmosphere, in X- and gamma rays, and all observatories in optical, radio, and high energy wavelengths on the surface of our planet. The energy range of the gamma ray bursts was actually 10^{54} erg, as predicted by Damour and Ruffini 24 years before.

3 ICRA and ICRANet.

In 1985, ICRA was founded by Remo Ruffini together with Riccardo Giacconi (Nobel Prize for Physics 2002), Abdus Salam (Nobel Prize for Physics 1979), Paul Boynton (University of Washington), George Coyne (Director of the Vatican Observatory), Francis Everitt (Stanford University), Fang Li-Zhi (University of Hofei). In 2005 ICRANet was born and dedicated to a complete understanding of these cosmic phenomena as well as to many other areas of research in general relativity, and to drawing out the appropriate consequences for the progress in research in theoretical physics and fundamental mathematics, as well as the conceptual consequences to understand the need for the existence of these objects that make life possible in our universe as we know it today.

All this was made possible though active collaboration with many leading international institutions and with the participation of a number of enthusiastic students and targeted research topics. But back to the frontiers of relativistic astrophysics.

ICRANet

University "Sapienza" of Rome	UNAM	CBPF	ASI	UFSC	FAPERJ	UFPB
UNS	UIS	BSU	Nice University	UFPE	NASB	IHEP
ENEA	IHÉS	ICTP	Ceará	CAPES	IFCE	ITA
NAS Armenia	INPE	SCSA	INFN	Pescara GARR	UFRGS	UNIFEI
Consiglio Nazionale delle Ricerche	Al-Farabi Kazakh National University	Universidád Autónoma Mertopolitana	LeCosPA	IFUFRGS	UERJ	Universidade Federal Fluminense

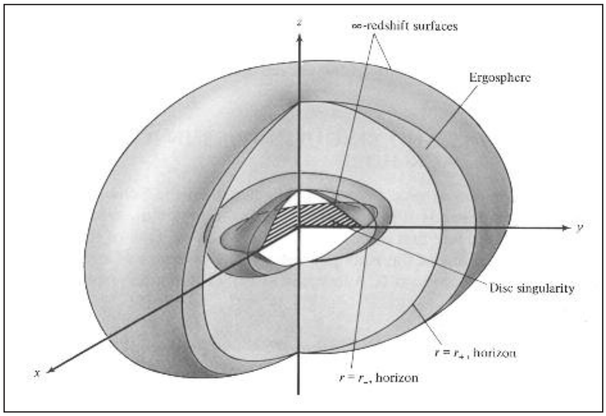
The institutions which have signed agreements with ICRANet.

4 The four fundamental pillars of relativistic astrophysics and the rise of a new physics.

In the first 40 years of relativistic astrophysics, four main pillars have been identified and explained in their conceptual aspects:

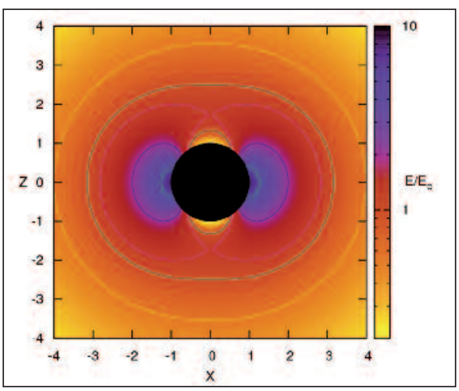
a) **Supernove**, with their role in forming the heavy elements, from carbon to iron to gold, essential to our lives. Their energy is of gravitational origin, and is generated in the final process of the collapse of a star which gives rise to a neutron star and violent neutrino emission. This has been verified recently with the capture in underground observatories in Japan of neutrinos emitted from a supernova in our own galaxy, and the AGILE satellite and the HESS telescopes have also observed additional emissions unexpected at high energies which provide the opportunity to discover new schemes of physics and astrophysics in these objects known and observed during the last millennium.

***b*) Neutron stars**, which offer the opportunity to study a system of fermions in self-gravitating equilibrium taking into account of all the fundamental interactions: relativistic, gravitational, nuclear and sub-nuclear. Today thanks to the progress of this knowledge, their critical mass appears to be far higher than originally predicted by Oppenheimer. From an observational point of view, rotating neutron stars, or pulsars, offer the possibility of establishing a system of standard clocks throughout our galaxy and in nearby galaxies thanks to the SKA program, far more precise than the most advanced atomic clocks on Earth's surface.



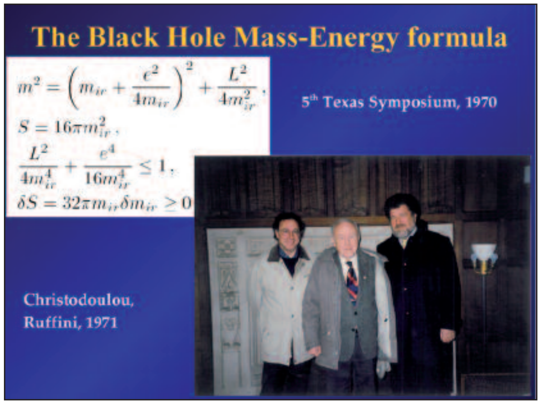
Structure of the horizons and ergosphere of a black hole. Image reproduced from H. Ohanian, R. Ruffini, "Gravitation and Spacetime", Cambridge University Press, 3 edition (2013)

***c*) Black holes** of tens of solar masses discovered in binary systems allow for the first time the study of totally new effects and not just perturbations, but in the "strong field" of Einstein's general relativity. i) The concept of "event horizon" has allowed us to explore for the first time with precise mathematical equations extensions of time coordinates and causal structures of our space-time that had only been guessed but never dealt with scientifically since the paradoxes of ancient Greek philosophy. ii) That a region of space-time could be reached but, once inside, no signal could be emitted to communicate observables to the outside, was one of the most unexpected messages. iii) The ability to extract rotational energy from a Kerr black hole marked one of the most revolutionary moments in physics, with the introduction of new concepts like "ergosphere", "dyadosphere" and "dyadotorus" which, like the term "black hole", required the introduction of new words in the dictionaries of all contemporary languages. iv) The black hole mass formula, and the fact that the gravitational binding energy of a particle



Structure of the dyadotorus of a black hole.

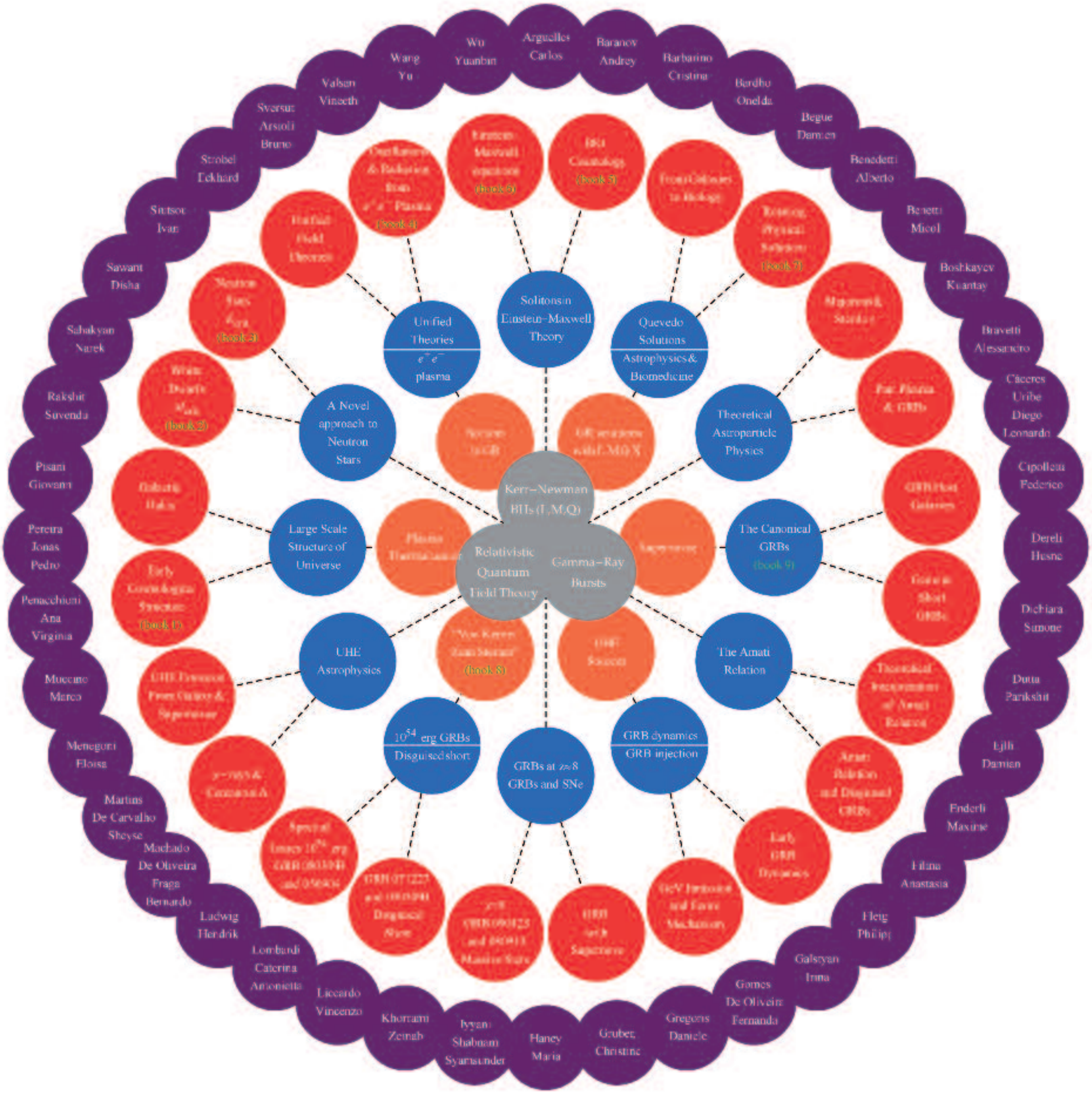
around a black hole could become comparable to the rest mass-energy ($0.42mc^2$), have by now entered all the physics textbooks, and represent major contributions of relativistic astrophysics to fundamental physics. All this was made even more important by the fact that black holes of far greater mass, of tens of billions of solar masses, have been discovered at the center of many galaxies, and are in fact the explanation of the quasars, discovered in 1962, which were one of the premonitory signs of relativistic astrophysics, like the above mentioned 3C273. Today a great deal of attention is devoted to the study of a possible black hole of 4 million solar masses at the center of our galaxy, which is currently in a quiescent phase.



The mass-energy formula for black holes.
In the picture, Christodoulou, Wheeler, Ruffini.

***d*) Gamma-ray bursts (GRBs)**, which created the biggest conceptual upheaval, represented the first application in physics and astrophysics to an object completely and only describable by relativistic field theories, starting from quantum mechanics, elementary particle physics, and general relativity. These objects have also represented a profound challenge to being understood that has been marked by three different phases: i) obtaining from observatories on Earth and in space evidence of new astrophysical phenomena and preparing the theoretical knowledge necessary for their study, ii) formulating a theory with accurate predictions and verifying their validity, and iii), probably the most difficult, conveying this new type of knowledge of relativistic astrophysics to classic astronomers and concepts of this new physics to traditional physicists. For a classic astronomer, used to study objects that vary on time scales of centuries or millennia, it is hard to fit into the study of these processes, among the most energetic and violent in the Universe, sometimes lasting less than a second. It is equally and even harder to believe that such a phenomenon, which lasts so little time when compared to those of our everyday experience, is not a simple phenomenon. The advanced technologies developed for ground and space telescopes have been able to examine the properties of GRBs over timescales from milliseconds to millionths of a second, and the more observations made on short time scales, the more new structures are found. These ordinary concepts of space and time are beyond the comprehension of non-experts in general relativity: a signal of a thousandth of a second measured by a telescope near the Earth corresponds, for some ultrarelativistic GRBs, to a signal that propagates for hundreds of light years in our Universe, which for a classic astronomer is clearly incomprehensible. And yet, in GRBs a new physics is observed daily that allows the acceleration of macroscopic masses of a fraction of a solar mass to speeds just below a few millionths of the speed of light through a neutral plasma of electrons and positrons, of matter and antimatter: some physicists are trying to reproduce such a process with powerful lasers in California and in the European ELI program, which is precisely the physics that characterizes the big bang.

Recognizing these four pillars of relativistic astrophysics has served as a stimulus to promote, within ICRANet, a number of other investigations on dark matter, the large-scale structure of the universe, the formation of active galactic nuclei in quasars, the big bang and the primordial stages of the Universe. One sees in the figure the related research themes and doctoral theses and published books.

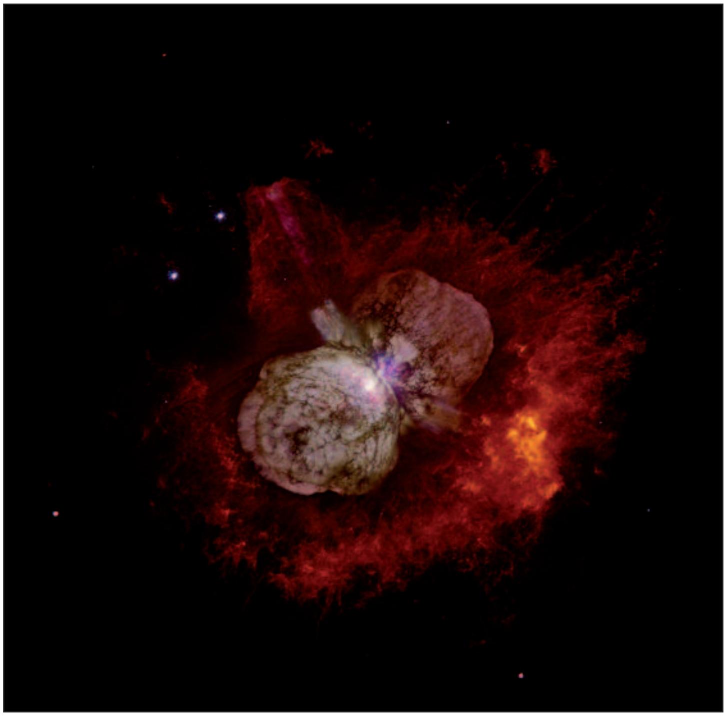


5 The frontiers: induced gravitational collapse, the “cosmic matrix” and the role of relativistic astrophysics.

But let’s return to the GRBs, where the greatest discovery was to come, unexpectedly, in a state that appeared at the beginning to be conceptually contradictory and deeply complicated, then day after day, hour after hour, it revealed all of its beauty and simplicity.

5.1 Gradual approach to the birth of a “black hole”.

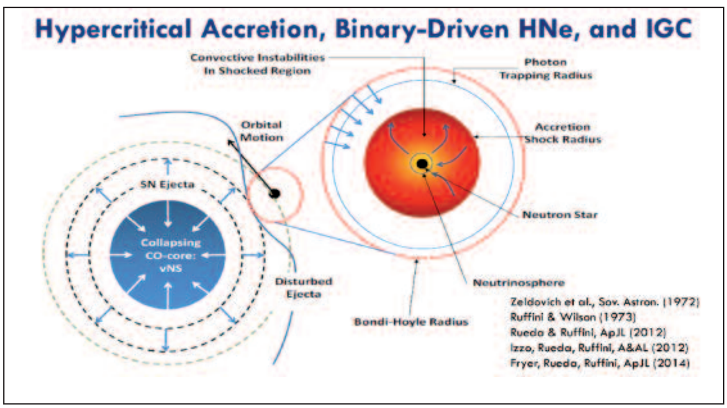
On April 25, 1998 a GRB erupted simultaneously with the explosion of a supernova. How is it that two objects so conceptually, energetically and structurally different can occur at the same point in space and at the same instant of time? Research on this continued for years, and only in the last few months has there been confirmation of the concept of "induced gravitational collapse". Only a few years ago it was still thought that a star of very large mass, about a hundred solar masses, evolves very rapidly towards the formation of a black hole: the more massive the star the more rapidly it evolves and collapses. However, only recently, thanks to the images of the Hubble Space Telescope, it was understood that practically all stars of large mass form binary systems, see the image of Eta Carinae. The approach to a black hole takes place along a very long path, strictly marked by a precise sequence of events which follow one another with increasingly pressing rhythms and each of which is marked by a different phase of gravitational collapse, with an influence of general relativity that becomes more and more pronounced until one finally reaches the birth of the "black hole" completely and uniquely carved into the structure of space-time. It is as if Nature chose to create a path that only people who can benefit from their knowledge of Einstein's general relativity can recognize the pauses and succession of events and fully perceive the uniqueness of this cosmic event, second only to the birth of the Universe.



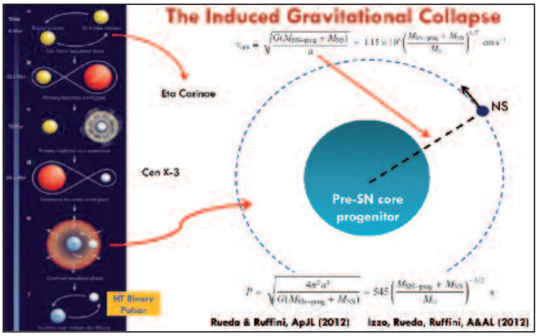
Eta Carinae. Credit: Hubble Space Telescope.

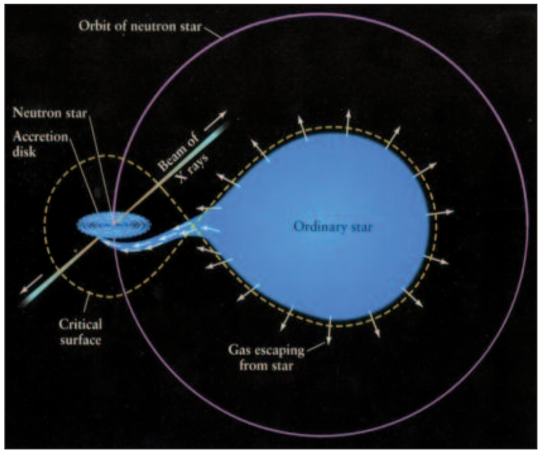
5.2 Induced gravitational collapse.

These studies were carried out mainly at ICRANet, with many young students and post-doctoral researchers who have made fundamental contributions that made them famous in the worldwide scientific community. Contrary to the traditional model, which sees a GRB as a single elementary process, it became

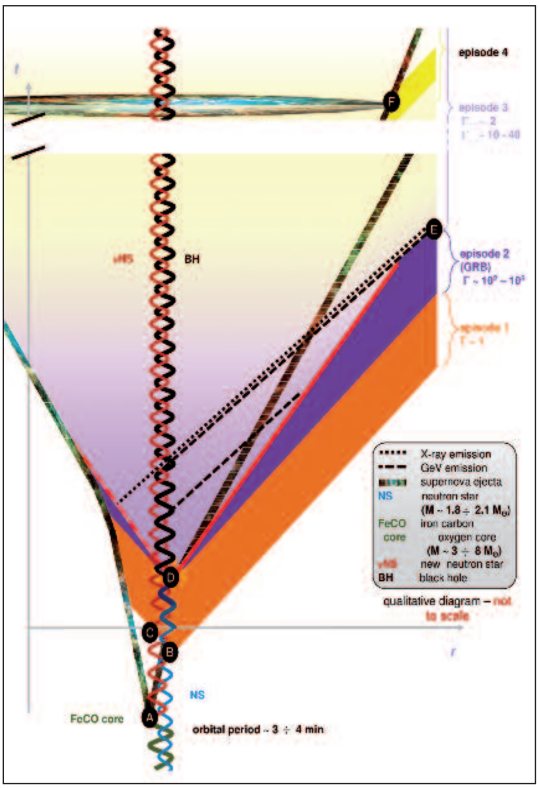


Accretion process and induced gravitational collapse in a binary system.





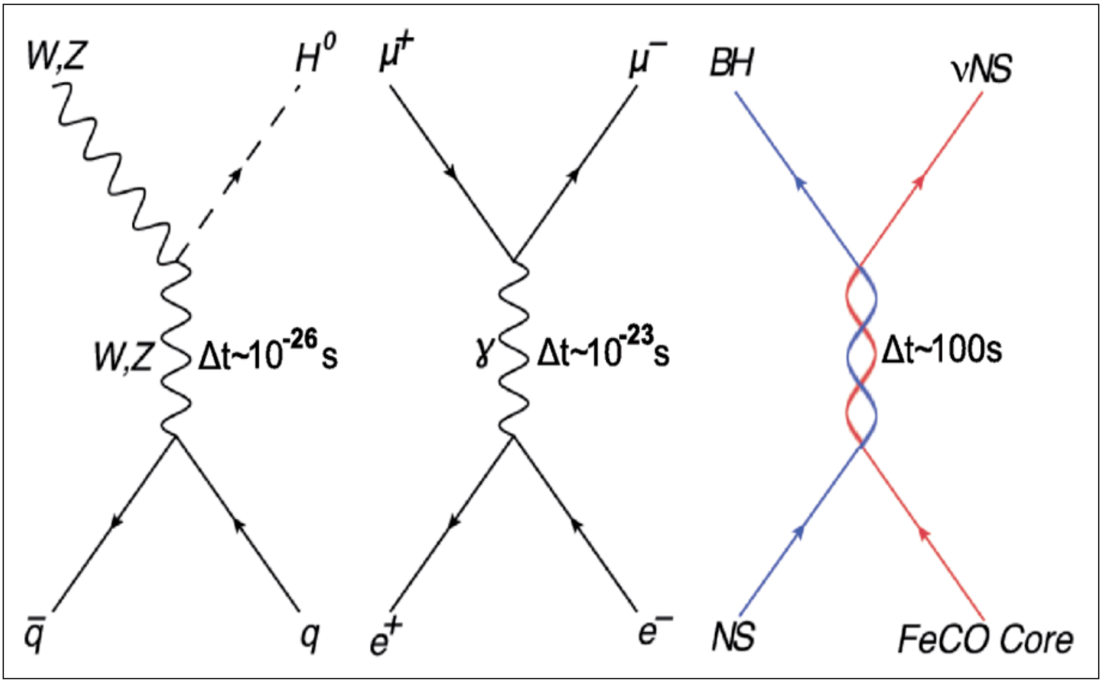
clear that in the ICRANet approach, all GRBs originate within binary systems formed initially by two massive stars and undergo a sequence of processes. This sequence starts from a binary system with a total mass of about 100 solar masses and: 1) of the two stars forming the initial binary system, the larger mass star evolves in a shorter time and in a first process of gravitational collapse, creates a supernova that gives rise to the birth of a neutron star: in this phase a binary system is formed like Cen-X3; 2) in a second phase the binary system, which now contains a neutron star and a massive star, evolves towards a much tighter system than the initial one with a shorter binary rotation period, until even the second massive star also explodes in a supernova; 3) in this process a second neutron star is formed, and the material ejected by the supernova accretes onto the first neutron star which reaches its critical mass and collapses gravitationally to form a "black hole"; 4) the second neutron star and black hole, both newborn themselves form a binary system that evolves with the emission of gravitational waves.



Space-time diagram illustrating qualitatively the different stages of the sequence of events which occurs during the emission of a GRB.

5.3 The "cosmic matrix".

This led to the concept of a "cosmic matrix", where four elementary systems interact together in a process that, seen by telescopes on Earth and in Earth orbit, only lasts three minutes. We are witnessing a process of transmutation that physicists had already met when they studied the decay of a neutron into a proton, an electron and an antineutrino: the famous "beta decay" considered by Enrico Fermi. The greatest challenge at the time facing the young people



The "cosmic matrix".

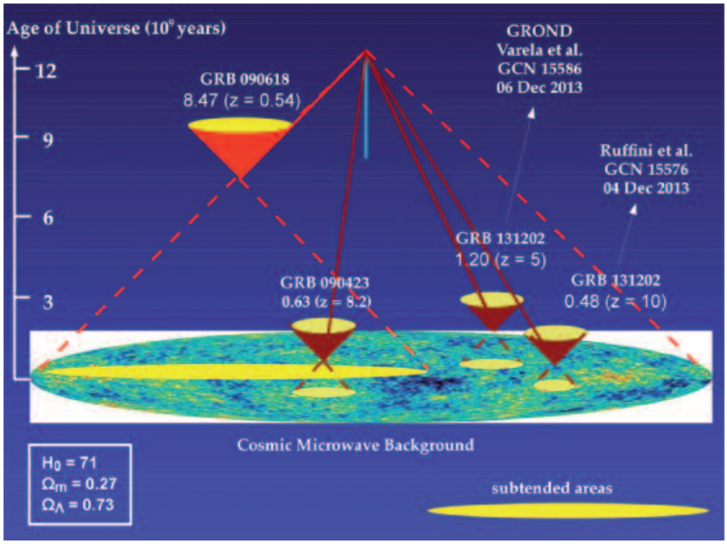
at via Panisperna was to understand how a neutron can give rise to a proton, an electron and an antineutrino: "Where were these particles before?" they asked, and Fermi explained it using the "S matrix" in quantum theory, introduced by John Wheeler and Werner Heisenberg, using the second quantization of Pasqual Jordan. Here we are now faced with a classic "cosmic matrix" in which a system of a supernova interacting with a neutron star gives rise to a black hole and another neutron star. The "S-matrix" is observed only thanks to particle accelerators in the world of the subnuclear dimensions of Fermi, i.e., namely a ten thousandth of a billionth of a centimeter. The "cosmic matrix" involves a phenomenon that in just three minutes emits the luminosity of all the stars in the universe: it is visible in the entire Universe and allows you to see the entire Universe! That a pair of electrons and positrons can be transmuted, according to the "S-matrix", into a pair of mu mesons was acquired from the experiences of Ada and then Adone in Frascati, and is now a culture in which all physicists agree. Now for astrophysicists and astronomers opens up the existence of processes totally new and unimaginable until a few years ago, allowed by the existence of a "cosmic matrix". This is the first time that science uses our entire Universe in conceptual formulation, in theoretical predictions and in the observations.

5.4 Signals from the entire past time of our universe.

The observations of GRBs have introduced a conceptually new situation. Being the most luminous events in the Universe, they can be seen from any distance all the way up to a cosmological redshift $z = 8$, corresponding to more than 12 billions years ago. In comparison, our Solar System, was formed only 5 billion years ago. The paradox is that GRBs have identical nature, although they originate from regions of spacetime which are not causally connected.

6 Other activities in ICRANet Centers.

We have in the preceding sections presented a general outlook of the ICRANet activities and illustrated just a special sector related to the four fundamental pillars of Relativistic Astrophysics: Supernovae, Neutron stars, Black Holes and the overall phenomena of GRBs which encompass all this knowledge and represents one of the most rapidly expanding frontiers of fundamental Physics and Astrophysics. These activities do not saturate the ICRANet scientific initiatives in all centers of the Network, which we plan to briefly illustrate in the following sections.



The light cones nicely illustrate the conceptually new situation introduced by the observation of GRBs. Being the most luminous events in the Universe, they can be seen from any distance all the way up to a cosmological redshift z = 8. The blue line represents the world line of our Solar System, which extends only for 5 billion years. The paradox is that GRBs have identical nature, although they originate from regions of spacetime which are not causally connected.

6.1 ICRANet Centers in Pescara, Rome and Nice.

Still in Rome and in Pescara we have to recall the fundamental research on the early Cosmology, made possible by the "transplant" into Pescara of the Russian School guided by Prof. Vladimir Belinsky, which has also been witnessed by the Marcel Grossmann award attributed to Prof. Yacob Sinai in the MGXIV (see sec. 1.2).

We recall in this context also the activities of the Seat of ICRANet at Villa Ratti in Nice. In addition to the activities based there for the IRAP-PhD program, there are activities connected with the ultra high energy observations by the University of Savoie and with the VLT observations performed by the Observatoire de la Cote d'Azur which involve the thesis works of IRAP PhD students. It is important to recall that the University of Savoie is the closest French lab to the CERN, the world center for particle physics and is directly involved in all the discoveries of heavy bosons W+-, Z and now Higgs.

Yacob Sinai.

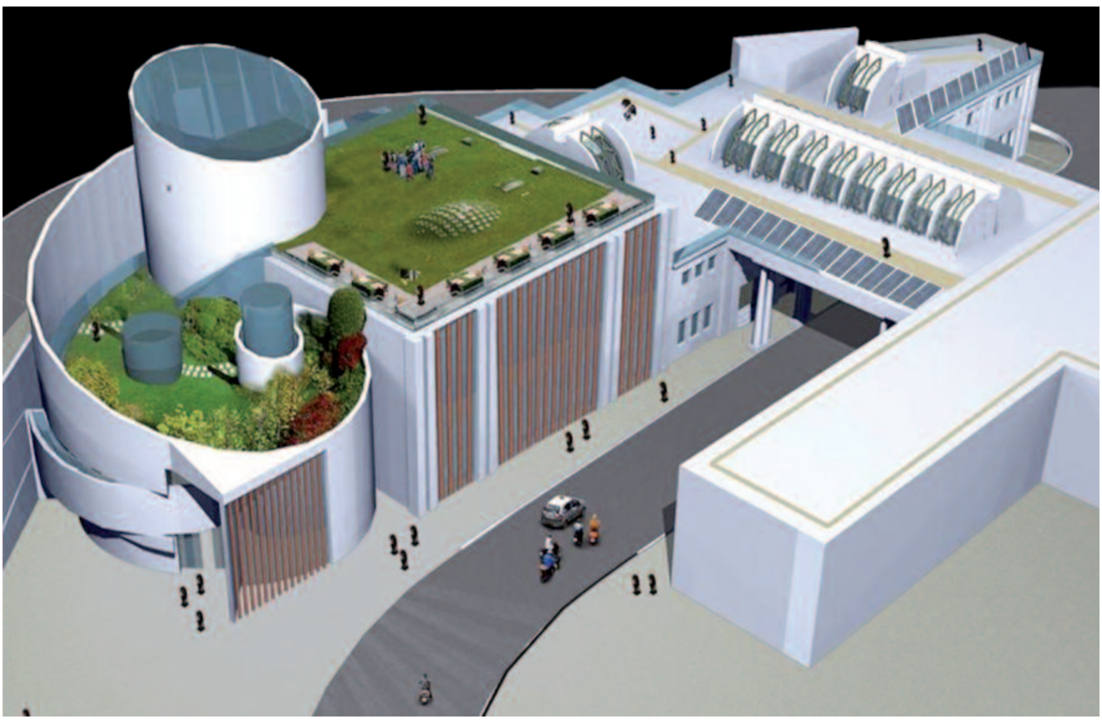
6.2 ICRANet Center in Armenia.

The MAGIC telescope.

Particularly vigorous has been the establishment of the ICRANet Center in Yerevan at the Armenian Academy of Sciences, with the signature and ratification of the Seat Agreement. Scientifically, the very successful presence of Prof. Felix Aharonian and Dr. Narek Sahakyan, with their students and collaborators in the MAGIC experiment, have already manifested its effectiveness in the second ICRANet César Lattes meeting, and created a vigorous presence of Armenia also within the ICRANet activities in Brazil.

6.3 ICRANet Center in Brazil.

We have already mentioned above the many activities planned in Brazil within the IRAP-PhD program, and the many ongoing research fronts with ten Universities and research centers in



The project by the Italian architect Carlo Serafini for restructuring the Cassina da Urca.

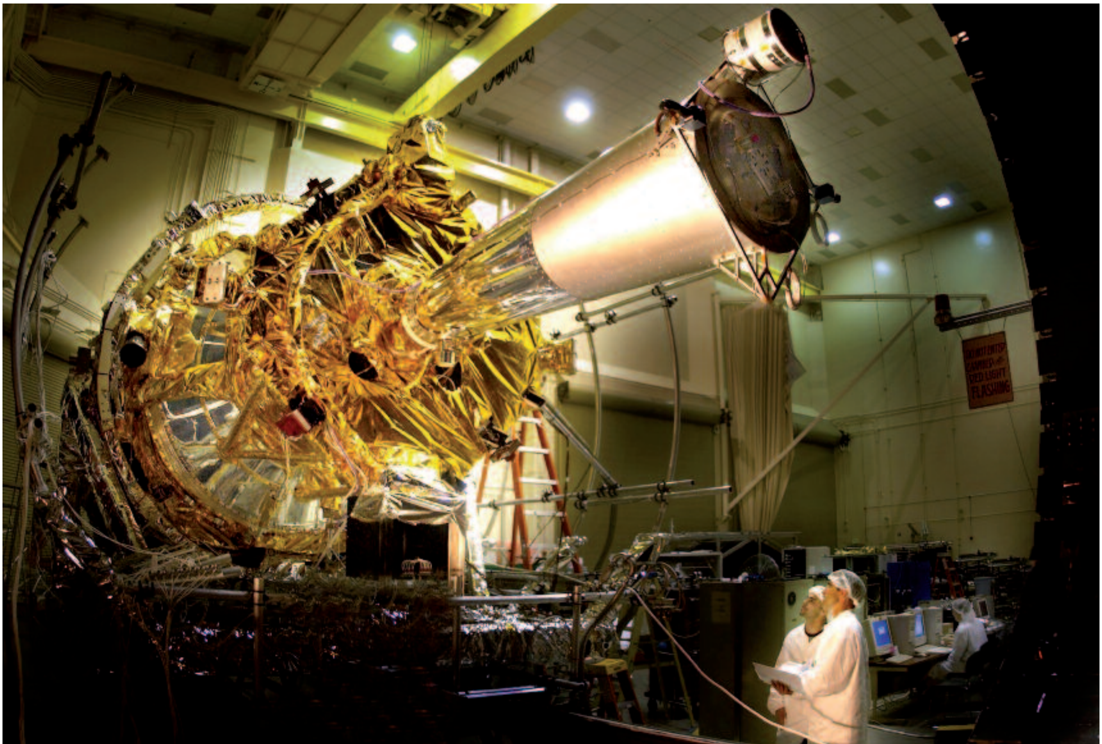
The BSDC web interface.

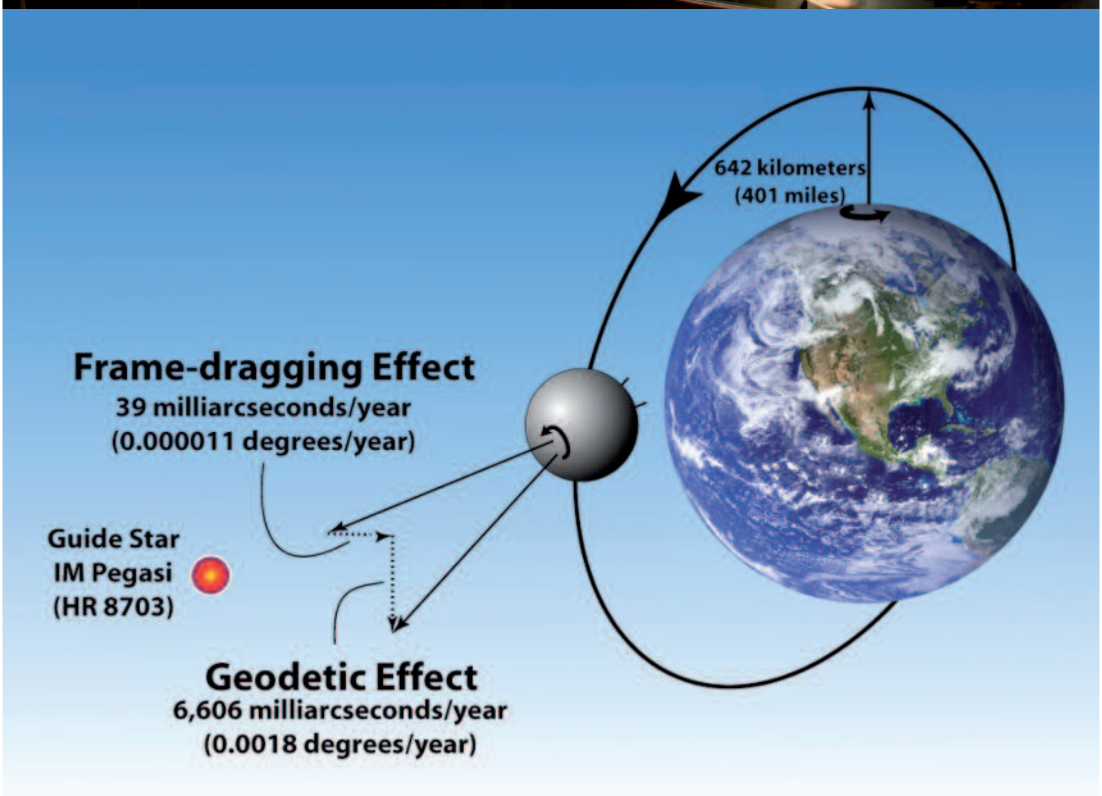
Brazil (see sec. 1.3). There are two specific programs which are underway: the possibility of restructuring the mountain side of the Cassino da URCA as the Seat of the ICRANet Center for Brazil and Latin America (with a project by the Italian Architect Carlo Serafini), as well as the ICRANet initiated building of the Brazilian Science Data Center (BSDC), a novel astrophysics data base, built following the concept of the ASI Science Data Center (ASDC) by the Italian Space Agency, which will consist on a unique research infrastructure at the interface between experimental and theoretical astrophysicists. The BSDC is currently being implemented in Brazil, at the Centro Brasileiro de Pesquisas Físicas (CBPF), and at the Universidade Federal do Rio Grande do Sul (UFRGS), and will be later expanded to all other Centers in Brazil as well as to the other Latin-American ICRANet Centers in Argentina, Colombia and Mexico: a unique coordinated continental research network is planned for Latin America.

To this aim, we are planning additional scientific activities in Colombia, where an agreement has been signed with the University of Bucaramanga (UIS). Similarly, there is the planning of the MGXIV satellite meeting in Mexico (see sec. 1.2), where agreements have been signed with the Universidad Autónoma Metropolitana (UAM) and with the Universidad Nacional Autonoma De Mexico (UNAM). In both cases the candidacy of having Colombia and Mexico joining ICRANet has been considered by the ICRANet Steering Committee with an extension in the Caribbean region.

6.4 ICRANet Centers in USA.

Turning to the USA, in the addition to the activities mentioned above, we recall the many actions promoted by Prof. Riccardo Giacconi, who was the first chairman of the ICRANet Scientific Committee and who ended his term in 2013 for reasons of age. We here recall a special activity of Prof Francis Everitt, responsible for the ICRANet Center at the Leland Stanford Junior University, and who is the currently President of the ICRANet Steering Committee: the conception, development, launch and data acquisition, all the way to the elaboration of the final data analysis, of the NASA Gravity Probe B mission. The results are going to be presented at MGXIV by Prof. Francis Everitt, who has achieved this mission, considered one of the most complex physics experiment ever performed. Still in USA we recall the collaboration with the University of Arizona in Tucson, with both the Physics Department, while Prof. Fang was there, and with the Astronomy Department, with Prof. David Arnett whose contributions have profoundly facilitated the disentangling and the understanding of the astrophysics of Super-

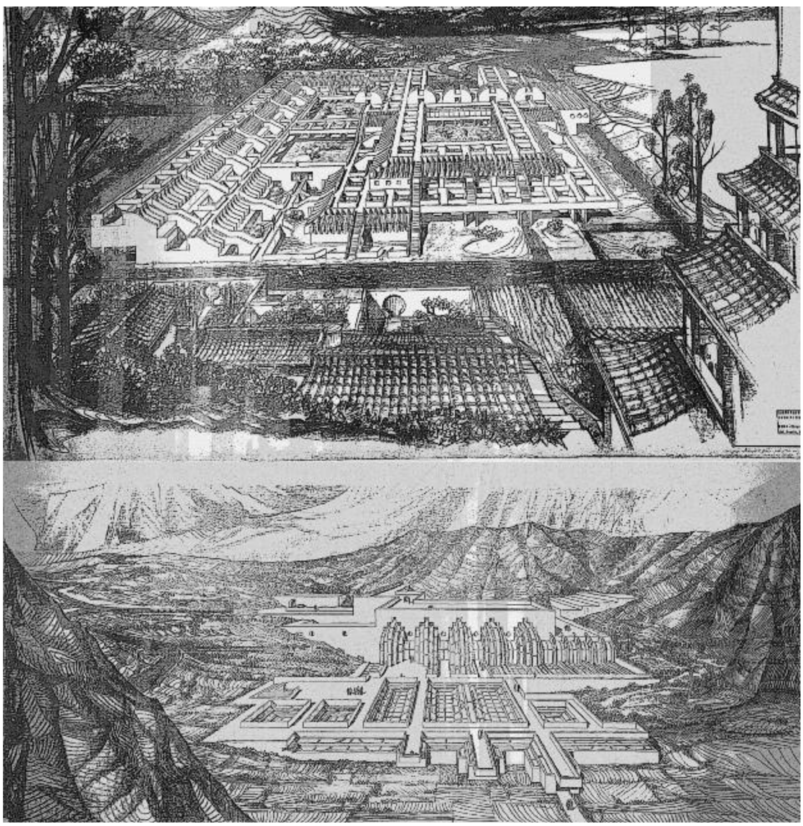




The Gravity Probe B experiment.

novae in the most recent scenario of GRBs which we have recalled above. Traditionally, within ICRANet, a special attention has been always given to the relations with China (see e.g. the recent Marcel Grossmann Award to C.N. Yang, also recalled in sec. 1.2). The ICRANet activities with China have seen the passionate action of Prof. Fang Li-Zhi as President of the ICRANet Steering Committee since its establishment in 2005 until his untimely death on April 7th, 2012. Of his activity we shall just recall the plans for the Matteo Ricci Center, the RI-MA-TO Center, which we epitomize in the image of the project of the great Italian architect Maurizio Sacripanti, which we are still planning to develop.

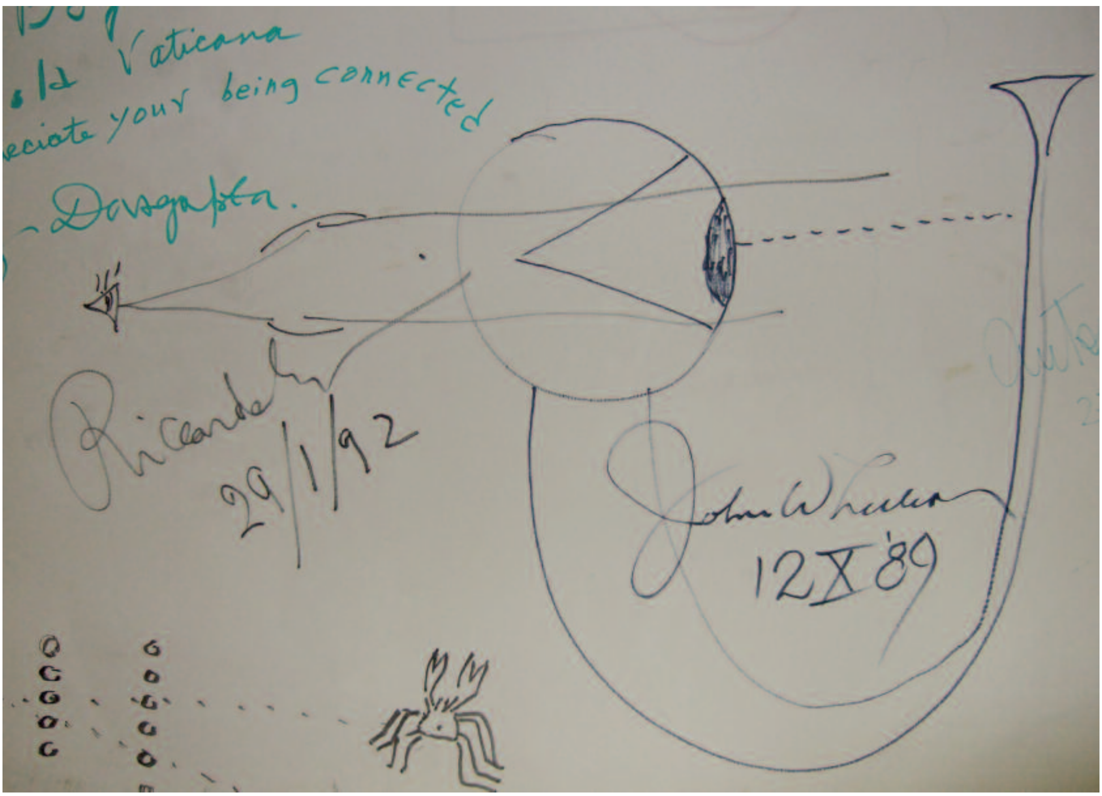
C.N. Yang receiving the Marcel Grossmann Award in Beijing in May 2015



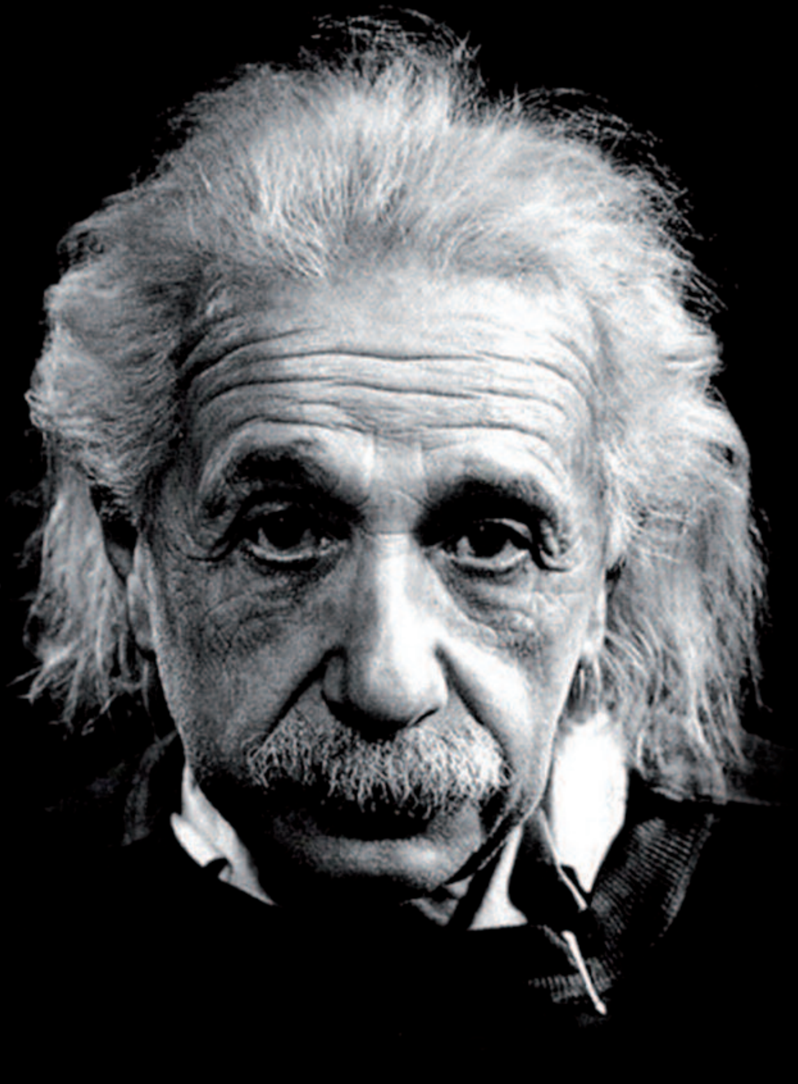
The plans for the Matteo Ricci Center, the RI-MA-TO Center, by the great Italian Architect Maurizio Sacripanti.

* * *

Relativistic astrophysics, whose "golden jubilee" we celebrate this year, has grown to the highest conceptual, geographical and technological levels. Rooted in the work of Galileo Galilei and Enrico Fermi it has found its own motivation in the conceptual revolution introduced by Albert Einstein in relativistic theories and in general relativity. Turning to the study of the most energetic events of the universe, it has explored all the "terra incognita" outside the local group of galaxies and going out to great distances and therefore backwards in time, it has permitted the exploration and understanding of all of our space time up to moment of the initial explosion: the "big bang". It has discovered new astrophysical systems, finding new and extreme conditions, and applying to them the knowledge of physics known on our planet has motivated their extension creating an expansion of basic scientific knowledge. All this was made possible through the use of advanced technologies, generating from them new ones, to reach the goal of more distant knowledge. This has led to an improvement in the quality of life on our planet. ICRANet participates in this by promoting research in its entire network, which is expanding day by day, preparing the formation of new scientists who can study and continue to promote the scientific, technological and conceptual development which found in the theory of general relativity and in the mind of Albert Einstein the highest expression of the "Homo Sapiens".



Signatures of John Archibald Wheeler, in 1989, and of Riccardo Giacconi, 10 years before receiving his Nobel Prize, in the laboratory of the G9 group in the Department of Physics of the University of Rome "La Sapienza". The universe through the eyes of man becomes conscious of itself, and the follow up annotation by Giacconi implies that man becomes even more aware by peering through the lens of the X-ray telescopes he invented for the NASA Einstein satellite.



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