AUGUST 2018

NEWSLETTER 50

Istituto Nazionale di Fisica Nucleare

INTERVIEW

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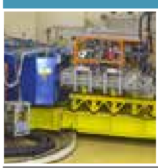

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EINSTEIN TELESCOPE: EUROPE MOVES TOWARDS THE THIRD-GENERATION GRAVITATIONAL-WAVE INTERFEROMETER

Interview with Michele Punturo, INFN coordinator of the project

It is called ET, Einstein Telescope, and represents the new scientific and technological challenge thrown down by Europe for research into gravitational waves. The project envisages the construction of a gigantic underground third-generation interferometer, which is already on the roadmaps of international institutions for scientific and economic development. ET is designed to be sensitive especially at low frequencies and it will enable regular, highly detailed observation of the gravitational waves generated by the coalescence of compact bodies, such as black holes and neutron stars, at cosmological distances, to bring to reality what is called high-precision gravitational wave astronomy. The observatory will be triangle shaped with three arms, each 10 km long, making a total perimeter of around 30 km, and will be positioned at a depth of between 100 and 300 metres, in order to insulate it against seismic waves. At present, the process has begun of submitting applications for sites interested in hosting the future laboratory, which will be one of the leading-edge infrastructures in scientific research worldwide. Italy is one of the candidate Nations, with the Sos Enattos site in Sardinia. We discussed the scientific and technological aspects of the ET project, and Italy's bid to host it in Sardinia, with Michele Punturo, the INFN coordinator of the ET project.

What is it that makes ET a third-generation interferometer? How will it improve research into gravitational waves?

The leap in technology and design brought about by ET will enable an improvement in sensitivity to a factor of 10, with special attention paid to low frequencies close to the Hertz. That corresponds to an observable volume 1000 times greater than second-generation detectors, when they reach their design sensitivity. For black holes, that means being able to see the whole history of the universe,

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studying the evolution of the black hole populations and therefore understanding the mechanisms that have led to the formation of the astrophysical bodies seen by LIGO and Virgo. By making detailed observations of thousands of coalescences of neutron stars every year, ET will reveal the mechanisms of nuclear physics at the basis of the existence of these stars, mechanisms that are also being investigated with other instruments at CERN with the LHC. In conjunction with traditional telescopes, in the area of multi-messenger astronomy, ET will be able to verify the cosmological model of the universe and contribute to understanding the enigma of dark matter and dark energy. But ET, with its wide spectral band, will also be an instrument of pure discovery, in other words observation of what we do not know today and that will surprise us.

What are the main challenges to be overcome in order to develop ET?
There are a lot of challenges: technological ones, having to improve by 3 times the performance of the apparatuses making up the current detectors, such as Virgo and LIGO. Those apparatuses represent the cutting-edge technology we have been able to develop so far, and we must now surpass ourselves by introducing new solutions (cryogenics, new materials) and improving existing ones. Engineering challenges: having to build an underground infrastructure, similar to LHC in terms of size, with extremely low levels of environmental noise and ensuring maximum safety for those working there. Scientific challenges: for handling of data and its scientific comprehension we will have to develop new algorithms for analysis, new models of sources and perhaps new theories. Financial and organisational challenges: ET is a pan-European project, worth billions of Euros, which will require the backing and cooperation of several nations and agencies.

What synergies are there with other INFN research sectors, such as, for example, high energy physics.
It is amazing how much synergy there is between the world of gravitational waves and nuclear and high energy physics, both from a scientific and technological point of view. As already mentioned, neutron stars are a nuclear physics laboratory where you can go to study matter in conditions of density that cannot be reached in laboratory settings and which could reveal new states of matter. Using the emission of gravitational waves from black holes (superradiance) or from coalescence of neutron stars can reveal the presence of light bosons or axions, which might help to explain dark matter or the mechanisms of cosmic inflation. Verifying general relativity or the alternative theories of gravity, which can be done with ET, may help to understand the cosmological model of the universe and the role of dark matter. On the other hand, the technologies developed in the world of high energy are vital for ET: cryogenics, ultra-high vacuum chambers of gigantic dimensions, control systems, high-performance electronics, data

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acquisition systems, computing. INFN has an incredible abundance of skills in all these fields, which has enabled it to take on a leadership role in high energy physics. ET needs these skills in order for it to be implemented and it will definitely ensure that INFN continues to take the lead, in the future of gravitational waves. The topic of ET synergies is on the agenda of the INFN next town meeting (6,7 September) dedicated to the new roadmap for particle physics.

What are the required features for hosting the infrastructure? Which are the candidate sites for hosting ET?
In this stage of conceptual study, we have carried out inspections at several potential sites and measured seismic and environmental noise. Some have shown to be potentially compatible with the set requirements, linked to low seismic noise, geological stability and low anthropisation. Attention has focused on three sites, in Hungary, in the Netherlands (on the border with Belgium and Germany) and in Italy, at Sos Enattos, in Sardinia.

Why has Italy identified Sos Enattos as the suitable site?
Because it meets the requirements of ET perfectly: Sardinia is extremely stable from a geological point of view and, at the Sos Enattos site, presents an extremely low level of seismic noise. Barbagia is one of the areas of lowest human density in Europe and, since human activity generates seismic noise exceeding a few Hertz, this means the site is extremely silent. The rock that could be excavated to house ET has excellent resilience and is extremely low on water, making it feasible to create the infrastructure. Sardinia also offers outstanding skill in the area of mining, so there is expert labour and know-how locally available.

What advantages are offered by hosting a scientific project like ET?
Research infrastructures act as a driver for cultural, infrastructural and economic development in the areas that host them. ET will bring development, both during its construction and in the operational stage: construction of the ET infrastructure is an activity involving high-intensity work for at least 5 years. Then, once operational, ET will attract scientists, engineers, technicians and administrative staff, to transform an area that is in serious economic hardship. And what is more, this presence will last over time, since gravitational wave observatories, unlike other types of infrastructures, require the presence of large numbers of people and the activities of ET are planned to last several decades. ET needs support infrastructures, such as high-speed internet connections, transport access and housing. It will also stimulate the growth of local business, for support and maintenance activities,

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or by virtue of technological spin-off. In particular, ET reconciles two aspects that appear to clash: development and environmental conservation. Indeed, the need for an area of low environmental noise levels will call for restrictions in the area around the interferometer, with careful selection of the type and impact of the new infrastructures.

Which countries are, at the moment, backing the Einstein Telescope?
Italy is at the forefront, thanks to the direct, original contribution of INFN, the support of the Sardinian Universities, above all Sassari, and the interest of the National Institute for Astrophysics (INAF). France is currently making a contribution through the collaboration between the Centre National de la Recherche Scientifique (CNRS) and the INFN in the European Gravitational Observatory (EGO), the consortium that runs Virgo, and that has also acted as coordinator for the study of the ET project. The Netherlands, through Nikhef, is pushing hard for the north-European site, involving some Belgian universities and, in Germany, the Max Planck Institute for Gravitational physics (MPG) and the University of Hannover. The Wigner Institute is sponsoring the site in Hungary. The Scottish and English universities (such as Glasgow, Birmingham and Cardiff) are backing the project heavily. In Spain, renewed interest is currently growing, especially in view of a possible site near the Pyrenees, in Canfranc.

The discovery of gravitational waves and the birth of the new multi-messenger astronomy are among the most promising lines of research for the coming years and Europe is investing in ET and the LISA project for a space interferometer in orbit around the sun. What are the other scientific communities in the world working on?
The pioneering ET project and the discovery of gravitational waves, together with the birth of multi-messenger astronomy, have stimulated the spread of the concept of detectors of third-generation (3G) all over the world. In the United States, the idea of a 3G detector is taking shape with the Cosmic Explorer proposal, a concept design recently financed by the National Science Foundation (NSF). That is why we have set up a global coordination project, called GWIC-3G, to unite and organise global efforts in the science, technology and management of the future network of third-generation observatories. Other players, such as Australia, have also directed their efforts and interest towards this coordination.

The upgrading of the detectors LIGO and Virgo is almost complete and they will soon be back in operation. What work is programmed for the second-generation interferometers and for ET?

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There is a good deal of continuity between the activities of Virgo and LIGO and the development of ET and all the other third-generation observatories. There is a coordinated upgrading and data capture plan for existing detectors which, in the next decade, will allow them first to reach their nominal sensitivity and then to go beyond that, with the installation of new technologies. The positive effect will be twofold. Firstly, the technologies installed for upgrading the second-generation detectors often constitute a first step towards the technologies required in ET: this is an excellent means of reducing the risks for ET. Furthermore, in its early years, ET will benefit from the existence of the (improved) second-generation network, working with it to locate the strongest sources, pending completion of the third-generation network. ■

GRANTS

ERC STARTING GRANT TO THE PROJECT MEGANTE

The European Research Council (ERC) has assigned to Gabriele Rosi, researcher of the Florence division of the INFN an ERC Starting Grant 2018 of € 1,550 million for the project MEGANTE (MEASuring the Gravitational constant with Atom interferometry for Novel fundamental physics TEsts).

MEGANTE is a five-year project on gravitational physics, which consists in the realization of a new experimental apparatus dedicated to the measurement of the gravitational constant. The new apparatus will have a higher sensitivity than the existing ones and will be realized using quantum technologies such as atomic interferometry. The measurement of the gravitational constant is considered in the metrological field the most difficult to achieve and it is the fundamental constant known with the greatest uncertainty. Many research groups, using 'classic' methods such as pendulums and torsion balances, are trying to push the relative accuracy to 10 parts per million (ppm). The idea of the MEGANTE project stems from the experience gained during the MAGIA experiment, conduct by the INFN and the European Non-Linear Spectroscopy Laboratory (LENS) of the University of Florence. MAGIA has directly measured, for the first time in the world, the curvature of the gravitational field. MAGIA which uses atoms in free fall instead of measuring probes of macroscopic mechanical objects, has reached a remarkable accuracy, but it will be MEGANTE to try the qualitative leap. ■

RESEARCH

ATLAS AND CMS OBSERVED "BEAUTY" PRODUCED BY THE HIGGS BOSON

It is a process, predicted by the Standard Model of particle physics and long sought: indeed it took six years to identify the decay of the Higgs boson in a pair of fundamental particles, called b-quarks (from beauty). The observation, presented on August 28th at CERN, by the scientific collaborations ATLAS and CMS at the LHC accelerator, confirms the hypothesis that the quantum field of the Higgs boson, which pervades the whole universe, also couples with the b-quark giving it a mass. Identifying this decay channel has been anything but easy: there are, in fact, many ways to produce quark b in proton collisions. This makes it difficult to isolate the decay signal of the Higgs boson from the "background noise" associated with these processes. In order to definitively isolate the signal, the ATLAS and CMS collaborations had to combine the data of the first and second run of LHC, including collisions at the energies of 7, 8 and 13 TeV. The result, both for ATLAS and CMS, lead to the observation of the decay of the Higgs boson in a pair of b-quarks with a statistical significance of more than 5 standard deviations (5 sigma). Both collaborations measured a decay rate consistent with the Standard Model prediction, within the current measure. ■

RESEARCH

CLAS EXPERIMENT: NEW RESULTS ON THE ROLE OF PROTONS IN THE NEUTRON STARS

Protons are responsible for the most energetic component of the heart of neutron stars. The study, published on August 13 in the scientific journal Nature, was obtained in laboratory thanks to the observations of the CLAS experiment at the CEBAF accelerator of the Jefferson Lab, in the United States, with the contribution of the INFN researchers. The CLAS experiment uses high energy electrons (5 GeV, billions of electron volts) to target different nuclei, such as carbon, iron and lead nuclei, with increasing number of nucleons and neutron-proton asymmetry. In the experiment, it has been possible to select for the first time the events in which a neutron and a proton were simultaneously detected both of high impulse, and therefore coming from interacting proton-neutron pairs. These observations showed that the percentage of high-pulse protons increases with the density of neutrons and, consequently, the average kinetic energy of the neutrons decreases in neutron-rich nuclei in favour of the energy brought by the protons. The results are relevant for the understanding of those extreme astrophysical systems, such as neutron stars, in which the number of protons, even if it is a minority, proves to be responsible for the most energetic part of it.

AWARDS

GIOVANNI GALLAVOTTI AWARDED WITH THE POINCARÉ PRIZE

Giovanni Gallavotti was awarded the prestigious Poincaré Prize, the highest international recognition for mathematical physics, awarded every three years. Gallavotti was awarded for his research and ‘outstanding contributions’ on statistical mechanics, quantum field theory, classical mechanics and chaotic systems, as stated in the motivations published on the Poincaré Prize website. Giovanni Gallavotti is professor emeritus at Sapienza University of Rome, is a member of the Accademia dei Lincei and since many years he conducts his researchers in association with the INFN. He was also president of the International Association for Mathematical Physics and is author of over 200 publications. In 1997 Gallavotti received the ‘National President of the Republic Award’ for the natural sciences section of the Accademia Nazionale dei Lincei and, in 2007, he was awarded the Boltzmann Medal, the highest international recognition for scientific contributions to statistical mechanics. ■

COMMUNITY

INFN HIRES 170 PEOPLE AMONG RESEARCH, TECHNOLOGICAL, TECHNICAL AND ADMINISTRATIVE STAFF UNDER PERMANENT CONTRACTS

At the end of July the Governing Council of the INFN approved the final ranking of candidates, including research, technological, technical and administrative staff, to fill 170 permanent positions as envisaged by the 2018 Budget Law. With the completion of this formal procedure, the INFN will be able to offer permanent contracts to a number of workers who have been with the Institute for several years on a fixed-term basis. The new contracts will officially come into effect as from 1 October 2018 and will increase the permanent workforce by around 9.5%.

INFN, therefore, can guarantee permanent employment contracts for members of staff who are already an integral part of research activities and have for many years been penalised by a short-sighted policy of almost zero staff turnover. In the past, that policy prevented these workers who will now have a permanent contract from taking part in competitions to fill permanent positions, the form of recruitment that INFN believes to be the best way for entering the world of research. This important step was made possible by the allocation of the stabilization fund, ratified by the Budget Law 2018, which will be slightly above 1 million euro in 2018 (starting from October). Then 3.4 million will be added from 2019, for a total of 4.4 million per year. When fully operational, the overall commitment for the staff hired will be of € 7.6 million, an amount therefore higher than the ministerial financing plus the due 50% co-financing from the INFN, which will take on the additional € 1 million needed annually. ■

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FROM SUPERNOVAE TO RADIOPHARMACEUTICALS: THE ENHANCED ACCELERATORS OF THE LEGNARO LABORATORIES

Understanding the processes that lead to the formation of heavy nuclei in the forging of stars is one of the scientific goals of the INFN's Legnaro National Laboratory (LNL), where the PIAVE (Positive Ion Accelerator for low VElocity ions) and ALPI (Acceleratore Lineare Per Ioni - Linear Ion Accelerator) are installed. In detail, a lead-206 (^{206}Pb) beam has been developed and accelerated at an energy of 1.2 GeV (Giga electron-volts), and then made to interact with a tin-118 (^{118}Sn) target. The lead beam was then used to investigate the reaction between heavy lead ions on tin, and the nuclei generated by this reaction were analysed using PRISMA: a magnetic spectrometer specifically designed and built at the LNL facility to measure in minute detail certain characteristics of the process that results in the production of heavy nuclei, such as the distribution of their mass, their nuclear charge and excitation energy. The nuclei produced were identified using specific detectors, mostly gas detectors, which provide the information that is needed to reconstruct the trajectory of the ions through the magnetic fields of the spectrometer. In recent times, this method has also been used successfully at the LNL facility to study the population of neutron-rich nuclei, by combining PRISMA with high-efficiency gamma ray detectors like CLARA and AGATA: this made it possible to associate the gamma rays, produced during nuclear reactions, with nuclei that had never been studied before. In the ^{206}Pb+^{118}Sn reaction, particular attention was paid to investigating the transfer of pairs of neutrons, which alters the isotopic composition of both the projectile and the target. The importance of this experiment lies in the fact that these processes, which involve pairs of nucleons, provide information about nucleon-nucleon correlations, which is fundamental in order to understand the structural properties of nuclei.
More in general, the use of lead beams and very heavy ions is important in order to study the population of neutron-rich nuclei. The detailed study of the mechanisms involved in the production of these nuclei

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and of their properties has important implications for astrophysics and for understanding the evolution of stars. In certain regions of the table of nuclides there is, in fact, strong competition between the beta decay process, which generates nuclei towards the so-called valley of stability (that contains the more stable nuclei), and the process known as "rapid neutron capture", which leads to the formation of increasingly neutron-rich nuclei in stellar structures, such as supernovae.

The beam used for the experiment was permanently generated by a 14.4 GHz cyclotron resonance source and then accelerated using radio frequency quadrupoles and quarter-wave resonators: all superconducting components, that operate at -269 °C, installed on the PIAVE and ALPI accelerators. Thanks to the combined use of PIAVE and ALPI, much of the measurement, which lasted 10 days, was performed with a beam current of more than 90 nA (nanoamperes). These measurements are the result of a major project to upgrade the superconducting RFQs, which now exceed the specifications for which they were designed and are more reliable. The system for controlling the cryostats and the cooling system of ALPI has also been modernised. The systems used to control beam radio frequency, transport and diagnostics have also been updated, and the accelerator has been aligned with laser technology so that the beam is transported more efficiently along the accelerator.

Many of these improvements have also been made with a view to using ALPI for re-accelerated exotic beams in the future multidisciplinary project at the Legnaro Laboratory, SPES (Selective Production of Exotic Species), which envisages the development of a highly innovative apparatus to generate and accelerate non-stable nuclei on fixed targets. SPES will pave the way for important research in the field of basic physics, to investigate nuclear reactions and nuclear isotopes about which little is known, as well as in other sectors such as the production of radiopharmaceuticals. ■

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Cover

Cryostat of the PIAVE accelerator at the Legnaro National Laboratories © LNL - INFN