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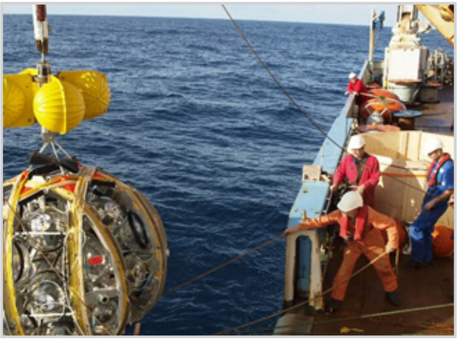


INFRASTRUCTURES

KM3NET: CONSTRUCTION OF THE NEUTRINO DETECTOR HAS COMMENCED

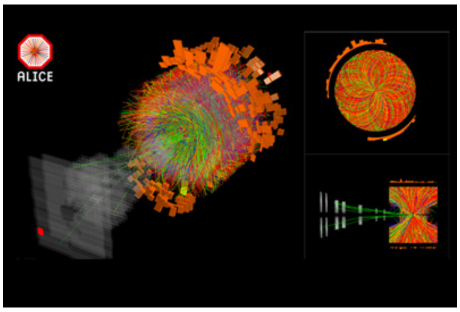
The first complete string of the KM3NeT neutrino telescope was installed on the seabed and connected to the shore in December. This marks the start of the construction of the experiment, which will be the biggest astrophysical neutrino detector in the northern hemisphere. It will occupy more than a cubic kilometre of seawater and comprise a network of several hundred vertical detection strings, each of which will be 700 metres tall and host 558 photomultipliers, the "eyes" of the detector. KM3NeT is an international collaboration in which Italian scientists, coordinated by the INFN, are on the front line. It is among the projects under selection for the new ESFRI (European Strategy Forum on Research Infrastructures) roadmap. The string, wound like a ball of wool, was transported to the KM3NeT-Italy site about a hundred kilometres off the coast of southern Sicily. It was then lowered into the water, anchored to the seabed at a depth of 3500 metres and connected to a junction box using a remotely operated submarine controlled from the boat. The junction box is connected by a 100 kilometre cable to the shore station located in Portopalo di Capo Passera in Sicily. The "ball" was then unwound and the structure assumed its definitive vertical "string" shape, kept taut by a submerged buoy. As soon as the string was powered on, the instruments at the shore station started to receive the first data from the particle sensors. ■

RESEARCH
THE PUZZLE OF THE ORIGIN OF ELEMENTS IN THE UNIVERSE

LUNA (Laboratory for Underground Nuclear Astrophysics) at the INFN Gran Sasso National Laboratory has recreated and observed a rare nuclear reaction that occurs in giant red stars, the type of star our Sun will eventually become. This is the first direct observation of sodium production in these stars, one of the nuclear reactions that is fundamental for the formation of the elements that make up the universe. Specifically, LUNA is the first experiment to have detected three "resonances" (an increase in the number of reactions observed over a small energy range) in a reaction in the neon-sodium cycle which leads to the production of sodium in giant red stars and the release of energy.

LUNA is a compact linear accelerator. It is the only one in the world installed in an underground facility, where it is shielded against cosmic rays and thus able to observe rare processes. The aim of this experiment is to recreate the energy ranges of nuclear reactions by going back in time to one hundred million years after the Big Bang, to the formation of the first stars and the start of those processes that, in a way we still do not fully understand, gave rise to the huge variety in the quantities of the elements in the universe. The experiment thus studies the nuclear reactions that take place inside stars where, like in an intriguing and amazing cosmic kitchen, the elements that make up matter are formed and then driven out by gigantic explosions and scattered as cosmic dust.

LUNA is an international collaboration involving some 50 Italian, German, Scottish and Hungarian researchers. This recent result was published in *Physical Review Letters* in December. ■



RESEARCH
CERN STARTS COLLIDING IONS AT RECORD-BREAKING ENERGIES

After the restart of the LHC (*Large Hadron Collider*) in June 2015, with a record-breaking collision energy of 13 TeV, and its first months of data taking with proton collisions, the super accelerator at CERN in Geneva is moving to a new phase. Inside the LHC's beam pipe, the 27 km magnetic ring that lies at a depth of 100 metres beneath the French-Swiss border, the first lead ion collisions at an energy of slightly more than PeV (100 eV) have started. This is the highest collision energy between nucleon pairs reached in an experiment in collisions between nuclei (5 TeV per nucleon).
Data from these experiments will be collected for one month by the LHC's four experiments, ATLAS, CMS, ALICE (specifically designed to study collisions of this type) and LHCb, which is recording data from collisions between ions for the first time. These collisions will allow physicists at CERN - including around 1500 from Italy, half of whom coordinated by the INFN - to study a state of matter, called the quark-gluon plasma, a soup of particles that existed briefly a few millionths of a second after the Big Bang. These collisions will allow scientists to recreate the conditions that were present in the very first moments of the universe, and to study their properties in the laboratory. ■

INDUSTRIAL COLLABORATIONS
A PIECE OF ITALY IN THE INTERNATIONAL Mu2e EXPERIMENT AT FERMILAB

ASG Superconductors based in Genoa, Italy, was recently awarded the contract to build one of the three magnets for the international Mu2e (Muon to electron) experiment at Fermilab, which will study the conversion of muons to electrons. The contract reflects the successful partnership between fundamental research and industrial research. Mu2e is part of the international research programme to study rare process that violate the law of lepton number conservation and cannot be explained by the Standard Model of elementary particles, and so require us to push the frontiers of our current knowledge. The Mu2e collaboration comprises approximately 200 scientists from 33 institutions in five countries: the US, Italy, Russia, Germany and the UK. The superconducting magnet system is at the heart of the experiment and will have a key role in its performance. The transport solenoid produced by ASG is the central of the three magnets and is made up of 27 modules. It's task is to select and separate the negatively and positively charged particles. It is long enough to allow all the particles that produce spurious signals to decay and thus create a "pure" beam of negative muons. The solenoid prototype was developed by the INFN team in Genoa and features the use of innovative construction technology. The module, produced by ASG Superconductors within the specified time and budget constraints, was subsequently tested at Fermilab, where it was found to exceed its performance specifications. ■

» INTERVIEW

EUROPE DESIGNS THE SUPERCOMPUTERS OF THE FUTURE

Interview with Piero Vicini, coordinator of the European supercomputer project ExaNeSt for the Italian INFN

A billion billion calculations per second (that is a one followed by 18 zeros). Such is the computing power of the supercomputers of the future. Developing them is the ambitious goal of a European project now set to get underway. The project is called ExaNeSt, European Exascale System Interconnect and Storage. Among its various Italian partners are the INFN - with the CNAF (National Centre for Research and Development in Information Technology) and the Rome division at the Sapienza University of Rome - the Italian Institute for Astrophysics (INAF), eXact LAB and the Italian branch of ENGINSOFT.
Piero Vicini is the project coordinator for the INFN. We asked him to explain why we need increasingly high-performing supercomputers in the so-called era of Big Science.

Can you tells us what the ExaNeSt project is all about?
ExaNeSt is a research project funded by the European Commission as part of the Horizon 2020 framework programme. It will contribute to the development of large-scale parallel HPC (High Performance Computing) systems. Production should start within the next five to seven years. We expect these systems to reach one ExaFLOPS, where FLOPS stands for FLoating point OPerations per Second, and the prefix "Exa" indicates 10^{18}, the equivalent of a 1 followed by 18 zeros. Put simply, we are talking about a computing system capable of performing a billion billion arithmetic operations per second, that is, a million times more powerful than the latest generation PCs available today.
The acronym "NeSt" in the name of the project refers to the scope of application, namely Network and Storage: ExaNeSt will develop and prototype innovative technological solutions for the processor-to-processor interconnection network and distributed data storage architecture.

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What is the INFN's role in this project?
In the ExaNeSt project the INFN's supercomputer technology group in Rome (APE) and the CNAF in Bologna are working together within the framework of a heterogeneous and multidisciplinary international partnership to achieve some extremely innovative results. The partnership includes research institutes, universities and industries from seven European countries (Italy, Greece, Great Britain, France, the Netherlands, Germany and Spain) with many years of experience in the development and use of extreme-scale HPC systems.
The INFN will contribute to all stages of the design process, assuming leadership and management responsibilities for many activities: from the design and implementation of the interconnection network and distributed data storage system, to the optimisation of full-scale scientific applications using the hardware platform prototype.

How do supercomputers work and why is their use of such importance in the era of Big Science?
An HPC supercomputer can be defined as a very large group of calculation nodes composed of high-performing processors that can be coordinated and synchronised and work in parallel to solve a numerically complex computational problem. Hence, it is clear that the efficiency of the processor-to-processor communication network and the architecture of the distributed data storage system affect the overall performance of the supercomputer. That is why it is so important to have properly designed and efficient interconnection networks and data storage systems.
The constructive efforts to develop systems to this degree of complexity are necessary because with this level of computing power not only will we be able to solve some computational problems that persist in fundamental physics, but we will also be able to address some large-scale scientific applications with a huge social impact. These include, for example, the discovery of new drugs using "ab-initio" molecular simulations, more complex and accurate meteorology and climatology models that will improve our understanding of climate change and allow us to have more accurate medium and long-term weather forecasts, the simulation and study of the properties of new materials, the simulation of neural networks on a big enough scale to obtain results that can be compared with measurements obtained from in vivo experiments.

What are the applications of ExaNeSt in physics?
The list of applications is long and reflects the heterogeneous nature of the project's partners. In terms of developing the system, it will promote a virtuous cycle of interaction between those designing and building the machine and those who will have to use it efficiently in future. They include, for example, the INAF, which is contributing with numerical cosmology and astrophysical simulation codes, simulations of materials science and climatology by ExaCtLab, and computational fluid dynamics engineering codes (ENGINSOFT). The INFN will contribute with simulation codes for theoretical physics and a large-scale neural network simulation application.

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It is important to underline the importance of the project's Italian application partners, who bear witness to Italy's expertise in the production of numerical simulation codes, despite structural difficulties that have hampered research in this country in recent years.
In an initial phase of analysis and selection, a set of applications will be selected on the basis of computational needs and characteristics, and on their social impact. These will then be the starting point from which to develop the programmes in order to test the platform.

How is this linked to the Human Brain Project?
The main points in common are the synergies in terms of objectives and activities. The INFN is coordinating the WAVESCALES project, which is part of the Horizon 2020 flagship Human Brain Project (HBP). Its goal is to simulate a large-scale neural network, focusing in particular on the propagation of brain waves during deep sleep and anaesthesia, and in the waking state. This application is of great importance, both for its social implications and as regards the system architecture, as it introduces some very interesting aspects. The programmes we will develop in WAVESCALES will be the starting point for developing the code to simulate neural networks that will be used to test the ExaNeSt prototype.

Does the INFN have a tradition of working in this sector?
Since the 1980s, drawing on a brilliant idea of Nicola Cabibbo and Giorgio Parisi who, in turn, were encouraged and supported by a group of young physicists who were particularly interested in computational physics and informatics, the INFN has developed four generations of supercomputers dedicated to theoretical physics calculations. The first was APE (*Array Processor Experiments*), which was for many years the scientific/technological benchmark for the international community involved in the development of supercomputers for scientific computing. Other technological activities aimed at improving scientific calculation systems have been developed in recent years. These include interconnection networks for PC clusters accelerated by GPU (APEnet), and low latency systems for readout by detectors for HEP experiments (NaNet). Furthermore, the INFN's previous collaborations with industry and its focus on fostering the transfer of technology - with Finmeccanica/QSW in the mid-1990s and with Eurotech in the 2000s, to mention just a few - have been fundamental for assuming a key role in the ExaNeSt collaboration, in which industry plays an important part.

What results do you expect to achieve by the end of the first three years, and what are the prospects for the future?
The first three years of the European Commission's plan are just the first stage of a cycle that will last between five and eight years, during which Europe will seek to acquire a more important role in

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the global market of supercomputing technology. In this initial stage we will analyse the enabling hardware and software technologies. This should be followed by at least two more stages that will concentrate on the development of pre-competitive systems and their industrial production and placing on the market. This represents a challenge for the giants in the sector in existing markets such as America and Japan, as well as in emerging countries, especially China.

At the end of the project, the ExaNeSt system prototype should permit us to embark on the pre-competitive development stage and then start on production engineering. In this context, the INFN will once again have a role in the HPC systems of the future, in terms of ideas and the capabilities to implement innovative, non-conventional solutions. ■

FOCUS ON

THE FIRST STEP TOWARDS OBSERVING GRAVITATIONAL WAVES FROM SPACE

At 5 am Central European Time on 3 December, LISA Pathfinder (*Laser Interferometer Space Antenna Pathfinder*) took off from the European spaceport in French Guiana. LISA Pathfinder is the technological forerunner of eLISA (evolved LISA), the spatial interferometer for detecting gravitational waves and the third of the ESA's large missions in its Cosmic Vision scientific programme. A few weeks ago LISA Pathfinder was placed in an elliptical orbit at a distance of between 200 and 1540 kilometres from Earth. Over the next few weeks the probe will move from this transitional "parking" orbit to reach its final position where it will orbit about the L1 Lagrangian point, at about 1.5 million kilometres from Earth, locked in a gravitational equilibrium between the Sun and the Earth.
Built by the ESA with the fundamental contribution of the ASI and in collaboration with the INFN and the University of Trento, LISA Pathfinder has the ambitious task of opening the way for observing gravitational waves from space, a mission that will start by 2034 with the launching of eLISA. Once complete, eLISA will be a highly valuable observatory for astrophysics, cosmology and general relativity and will enlarge our understanding of the evolution of the universe, when galaxies, stars and planets started to take shape. Gravitational waves are emitted by all bodies, whether visible or not. They record the motion of objects in the most remote depths of the universe and carry the information to us, like the sounds of the night, capable of passing undisturbed through any kind of matter or energy. LISA Pathfinder will thus pave the way for this new mission that will bring about a profound revolution in the fields of astrophysics, astronomy and cosmology.
The probe will serve as a testbed for the technology needed to observe gravitational waves from space. Its main aim is to test the possibility of monitoring and measuring the movement of two test masses (gold-platinum cubes) placed in a near-perfect free-fall, with extremely high precision. LISA Pathfinder's high-precision instruments will be able to detect the ripples in the fabric of space-time caused by collisions between massive celestial bodies. Scientists have calculated that such events

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should produce a relative motion between the LISA Pathfinder cubes of the average size of an atom.
But the astonishing precision of this probe and the distance of its orbit are only a fraction of those that will characterise the full-fledged eLISA observatory. Conceptually identical to the large terrestrial interferometers like Virgo - the interferometer operated by the European Gravitational Observatory (EGO) based in Càscina - eLISA will consist of three satellites placed at the vertices of an equilateral triangle, one million kilometres apart. Each satellite will contain the same masses of gold and platinum that are currently less than one metre apart in LISA Pathfinder. The three satellites will follow the Earth in its orbit, sending laser beams from one to the other so that the distance between each pair of satellites is constantly measured. By measuring these distances, and any differences caused by the arrival of a gravitational wave, it will be possible to detect the presence of such waves and measure their intensity.
The high-precision instruments that will encase the test masses in LISA Pathfinder, inertial sensors, were built by CGS (Compagnia Generale per lo Spazio), as industrial prime contractor for the Italian Space Agency. They were designed by researchers at the University of Trento and the INFN. The INFN is currently contributing to the project through the TIFPA (*Trento Institute for Fundamental Physics and Applications*), the new centre of excellence established in 2013 in Trento. ■

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