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Istituto Nazionale di Fisica Nucleare

INTERVIEW

NEWS

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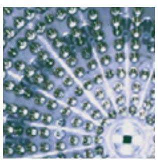

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THE NEW ERA OF MULTIMESSENGER ASTRONOMY

Interview with Marica Branchesi, astrophysicist, researcher at the Gran Sasso Science Institute and associated researcher at the INFN Gran Sasso National Laboratories.
Head of the LIGO/Virgo team committed to alert partner observatories in case of gravitational waves signal

16 October 2017 was a historic day, because the joint announcement of the first detection of gravitational waves with observation of the electromagnetic counterpart of their source, marked an epochal change in our way of studying the universe with the beginning of the era of multi-messenger astronomy. We got one of the protagonists of this result to tell us what happened and what is its meaning: Marica Branchesi, astrophysicist, researcher at the Gran Sasso Science Institute (GSSI), associate at the INFN-Gran Sasso National Laboratories. Branchesi was also among the scientists who presented the result during the LIGO and Virgo conference, held in Washington at the National Science Foundation (NSF), at the same time as many other conferences worldwide, including that in Italy of the INFN, of the National Institute of Astrophysics (INAF) and of the Italian Space Agency (ASI), in collaboration with the Ministry of Education, University and Research (MIUR).

I would like to start with the facts: what happened on 17 August?
Around 2:40 pm the phone rang, gravitational wave alert message. As coordinator of the LIGO and Virgo collaboration team which sends alerts to telescopes, I immediately connected to the computer in conference call with data analysis experts and scientists at the three sites, Cascina, Livingston and Hanford. A signal in the data collected by LIGO and Virgo coming from the coalescence of two neutron stars, a gamma burst seen by the Fermi satellite two seconds after the gravitational wave signal. Four hours later we were able to send a precise position, the source was in the southern hemisphere, ideal for the Chilean telescopes that start to observe at dusk. The Virgo interferometer, in Cascina, funded mainly by INFN and CNRS, played a key role in the discovery, allowing signal localisation. From hundreds, thousands of square degrees of signals from star mass black hole systems detected by the LIGO detectors

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alone, the triangulation of the LIGO and Virgo network and location of the source in the "blind" zone of Virgo provided a position of only 30 square degrees. The distance of the astrophysical source was found to be pretty close, 40Mpc, 130 million light years from us. The region of the universe where to look for the counterpart was relatively small and close, a region where we know the distribution and properties of the galaxies. In one of these galaxies, NGC4993, after 11 hours the first light in the visible band was detected as a very bright object (hundreds of millions of times the brightness of the sun) not present in images prior to the coalescence. NGC4993 is located at the same distance as the gravitational wave signal. From that moment, 70 observatories, involving 100 instruments, ground telescopes and satellites, observed NGC4993 for weeks. The optical emission showed a rapidly cooling object, initially a rapidly diminishing blue emission, and an evolution towards red and infrared in a week. From the same position in the sky, 9 days later, an X signal was detected and 16 days later a radio signal.

How did you live that day?

It was extremely exciting: the dream for which we had been working for years was in front of us.
Feeling part of history, of an epochal discovery... the beginning of an adventure that in the coming years will lead us to so many other discoveries. At the same time, the need to be operational, efficient, lucid: coordinate LIGO and Virgo operations to send useful information to astronomers and be ready to respond to astronomers focusing satellites and telescopes. I am an astronomer and have also participated in the INAF observations with the ESO telescopes. every day started with new data to understand the physics of neutron stars and the mechanisms of sound and light emission. The largest observational campaign ever carried out on all spectral bands. The most beautiful gravitational and electromagnetic data I have ever seen. We had almost 100 seconds of gravity wave signals and all the colours of the coalescence of two neutron stars, the last moments of the dance of the two stars, the fusion into an ultra-dense object, probably a black hole, and the light of one the most energetic phenomena in the universe. In short, it was the best of our dreams...

How did the work proceed in these months to arrive at the announcement of 16 October?

The LIGO and Virgo collaboration worked to carefully analyse and verify all the results and write the articles. The astronomers continued to observe the gravitational wave source, the surrounding environment and the galaxy for weeks and will continue to do so for years. About 90 articles have already been published, 8 of which from the LIGO and Virgo collaboration. In particular, I was involved in the interaction with the astronomer groups and worked in the writing team (10 LIGO and Virgo scientists) which wrote the article with all the astronomer groups. An article signed by some 3500 authors, which marked the collaboration

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of thousands of scientists from six continents, the beginning of multi-messenger astronomy and of the work of a global network of observers. In the history of astronomy there are few articles written by different communities, this has unified the work of physicists, astrophysics, astronomers and theorists. For two months I slept little... and worked a lot, but what a great satisfaction!

What are the most significant scientific results presented on 16 October?

So many scientific results, impossible to define an order of importance. Many confirmations of ten-year-old theoretical models able to explain the set of data collected. At the same time, we are in the presence of a wealth of data whose details will require a great theoretician and other observations in the coming years to be interpreted.

It was the first observation of gravitational waves from the coalescence of two neutron stars, with detection of the electromagnetic counterpart in all spectral bands and identification of the host galaxy.

The gravitational event called GW170117 marks the birth of multi-messenger astronomy that uses gravitational waves and electromagnetic emission.

This observation also marks the beginning of cosmology with gravitational waves. The Hubble constant, i.e. the universe's expansion rate, was measured by combining the measurement of the galaxy's recessive velocity due to the expansion of the universe and the distance of the source measured by the gravitational waves. Moreover, it was the first observational evidence and definitive confirmation that the progenitors of short gamma ray bursts (duration of less than 2 seconds) are represented by neutron star coalescence, almost fifty years after their discovery by military satellites monitoring nuclear tests on Earth.

The gamma, X and radio signals measured are interpreted as Gamma Ray Bursts (GRB,) observed at larger angles than the emission cone. We are in the presence of the first observation of an off-axis GRB, am emission theorised for about two decades but never observed before.

The tiny 1.7 second delay between the gravitational wave signal and that of the gamma rays once again confirms that Albert Einstein was right: gravitational waves travel at the speed of light, like photons.

The colours observed from ultraviolet to infrared show (as predicted by the theory) that during the coalescence of two neutron stars, the mass ejected at extremely high velocity in the interstellar medium is the ideal site for the formation of heavy elements for rapid neutron capture. While the radioactive decay of such elements determines the visible emission observed (called kilonova): the universe is enriched with elements heavier than iron, including gold. Coalescences of two neutron stars are very rare events; in our galaxy they can happen a dozen times every million years, but the quantity of heavy elements that can be formed is enormous - for gold an amount equal to approx. 10 Earths is estimated. Our jewels very probably come from the coalescence of two neutron stars that occurred billions of years ago in our galaxy

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that dispersed heavy elements in the interstellar medium from which stars and planetary systems were formed.

What does it mean when we say that a new era for astronomy has been opened? What is multi-messenger astronomy?

Gravitational wave detectors are now able to observe millions of galaxies, which gives us the possibility to observe very rare, but crucial, events in the evolution of the universe. We now have a network of observatories able to give a more accurate position that allows traditional satellites and telescopes to capture the possible electromagnetic signal emitted by the astrophysical gravitational wave source. Now we can observe the universe with multiple messengers, gravitational waves and photons. Have a complete picture of black holes and neutron stars and their interaction with the environment. Multi-messenger astronomy uses waves and particles, including neutrinos, to observe the universe. For GW170817, neutrinos were not observed, but we hope to soon add this additional messenger to our observations.

LIGO and Virgo, having terminated RUN O2, have entered a new upgrade phase. What will be enhanced and with which scientific goals?

Detector sensitivity will be increased in order to observe a greater volume of the universe, reaching a sensitivity greater by a factor of at least 3 compared to that of the current network, a factor of 30 in volume. This will allow us to observe more neutron star and black hole coalescence signals and possibly observe new signals such as the coalescence of neutron star-black hole systems, the gravitational collapse of massive stars in our or surrounding galaxies, continuous pulsar emissions and stochastic signals. And like every time a new observation window is opened, I also expect exotic objects/signals. The closest goals are to have a mass and frequency distribution of black holes that will allow us to understand how they form and evolve. Have more observations in order to understand the structure of neutron stars and carry out general relativity tests.

What does it mean when we say that thanks to gravitational waves, we could get even "closer" to the moment of the big bang?

The difficulty of detecting gravitational waves is what makes them extremely special, interacting weakly with matter. Unlike photons, they are not absorbed, so they can come from distant regions of the universe and regions where photons cannot escape. We expect future detectors to be able to listen to gravitational waves produced directly by the big bang, providing us with direct information on the birth of the universe.

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What are the prospects for gravitational astronomy?

The LIGO and Virgo network has opened a window on the universe, but the observed frequencies and universe are relatively small. The Einstein Telescope project will allow us to increase the sensitivity by a factor of 10 compared to the Advanced detectors such as LIGO and Virgo, reaching the entire universe. This will allow us to observe many more events and observe them better. We will be able to study the cosmological evolution of gravitational sources throughout the cosmological history of the universe, study the populations of astrophysical sources and their evolution and do precision cosmology. The events observed by LIGO and Virgo will be able to be studied with a higher signal noise ratio allowing better location to search for the electromagnetic counterpart, detailed studies to understand the structure of neutron stars and possible deviations from general relativity. There will be a higher probability of observing signals of the gravitational collapse of massive stars, instability signals of neutron stars, continuous pulsar signals and stochastic signals. Going down to slightly lower frequencies, we can imagine to detect signals before coalescence and point telescopes in the fusion phase, with crucial information for understanding where and how the first multi-band electromagnetic emission originated. Space observatories such as LISA will open the low frequency band from milli-Hertz to 0.1 Hertz, with the possibility of observing large cosmological sources, the coalescence of more massive black holes that reside in the centre of the galaxies and observing them up to the time of their formation. We will be able understand how galaxies formed in the universe and how they have evolved. We will be able to follow stellar mass black holes in their slow orbiting one around the other or observe their fall into massive black holes. The multi-messenger network that has come to life with GW170817 is also a milestone for the future, in which similar observation campaigns will have to follow gravitational wave signals. Within twenty years time, we will have to think of observatory projects that allow combined observations to maximise the scientific return of every gravitational wave observation.

On 16 October, in the Washington conference, out of 11 speakers, four were Italian and all women. And also in the other conferences that were held at the same time, for example that of ESO in Europe, Italy and women were present. A satisfaction, and a significant and encouraging fact for many young women...

A great satisfaction and honour to be with six other women who have had fundamental roles in this discovery. Despite the difficulties, the gender stereotypes, science, and in particular (astro)physics, is also a woman (ed. science and physics in Italian are female nouns). You can be a woman, mother and scientist... for example, I am a mother of two beautiful children who were born with the gravitational waves, one two years and one ten months old. Before I started this job I would never have thought of being able

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to speak in front of hundreds of people in public, to go on air worldwide for a wonderful discovery... but all this has happened! To young female researchers I would like to pass the message that they must believe in what they do, work with passion, humility and honesty, without setting limits but pursuing great goals... because all their dreams can come true. ■

AWARDS

2017 NOBEL PRIZE FOR PHYSICS GOES TO BARISH, THORNE AND WEISS, REWARDING THE DISCOVERY OF GRAVITATIONAL WAVES

The 2017 Nobel Prize for Physics has been awarded to Barry Barish and Kip S. Thorne, both from Calthech, and Rainer Weiss from MIT, for their role in the discovery of gravitational waves, as promoters and founders of the LIGO (Laser Interferometer Gravitational-Wave Observatory) instruments, thanks to which the first measurement of gravitational waves was made on 14 September 2015, a century after their theoretical prediction in Albert Einstein's general relativity.
The announcement of the historic discovery of gravitational waves was made by the scientific collaborations LIGO and Virgo, in which Italy participates with the INFN, on 11 February 2016, during two joint press conferences, in the United States in Washington at the headquarters of the National Science Foundation (NSF), which finances the LIGO project, and in Italy at Cascina, where the European Gravitational Observatory (EGO) is located.
The first detection of gravitational waves took place on 15 September 2015 by the twin Advanced LIGO interferometers in the United States. During the following observation period, two further detections were announced. As from 1 August 2017, the VIRGO interferometer joined the two of LIGO in data collection: this led to a new observation of gravitational waves, announced on 27 September 2017, during a joint press conference of the LIGO-VIRGO collaborations that took place at G7 Science in Turin. With this first three-instrument detection, which allows the source of the gravitational waves to be located with unprecedented precision, we thus entered the era of the era gravitational astronomy, a completely new way of studying our universe. ■

Interviews https://www.youtube.com/watch?v=LSmBAlghjKo&list=PLbsqUzxZIcP7oL-LK2es61vaSrFkbbK_M&index=1

RESEARCH

INAUGURATION OF CUORE: THE COLD GIANT STUDYING NEUTRINOS

On 23 October, at the Gran Sasso National Laboratories (LNGS) of INFN, the CUORE (Cryogenic Underground Observatory for Rare Events) experiment, the largest cryogenic detector ever built, designed to study the properties of neutrinos, was inaugurated. In the first two months of data collection, the experiment has operated with extraordinary precision, fully satisfying the expectations of the physicists who built it and significantly restricting, already at this very first phase, the region in which to look for the rare phenomenon of double beta decay without neutrino emission, the main scientific objective of the experiment. Detecting this process would make it possible not only to determine the mass of neutrinos, but also to demonstrate their potential nature as Majorana particles, providing a possible explanation for the prevalence of matter over antimatter in the universe. The CUORE detector is a 741 kilogram giant implemented with a technology based on ultra cold cubic tellurite crystals designed to operate at very low temperatures: 10 thousandths of a degree above absolute zero (-273.15°C). Its structure comprises19 towers each consisting of 52 tellurite crystals purified from any contaminants. The most difficult technological challenge faced by the experiment was the implementation of the cryostat, able to keep the 19 towers suspended inside it at a few thousandths of a degree above absolute zero. The experiment works in extremely pure environmental conditions, in particular with very low levels of radioactivity. The cryostat is, in fact, shielded from the shower of particles coming from the cosmos both by the 1400 metres of rock of the Gran Sasso massif and by a special protective shield, made by casting lead ingots recovered from a Roman ship sunk over 2000 years ago, off the coast of Sardinia.
CUORE therefore uses a technology unique in the world for unprecedented precision, a result that has required more than ten years of work. The prototype called Cuore-0, consisting of a single tower in operation from 2013 to 2015, preceded CUORE and its first results were announced in April 2015.

COMPUTING

EU INVESTS IN THE EUROEXA PROJECT FOR EXASCALE EUROPEAN SUPERCOMPUTERS

A first prototype for an all-European, in terms of both design and technology, supercomputing infrastructure. This is the goal of EuroExa, a project funded with 20 million euros under the H2020 research programme and just launched by the sixteen European institutions that participate in it, including the INFN and the National Institute of Astrophysics (INAF) in Italy. The institutions of the EuroExa consortium met at the Supercomputer Centre in Barcelona to confirm the start of the EuroEXA project and, at the same time, mark their participation in the development of demonstrators of parallel calculation systems scalable up to the ExaFlops level, i.e. capable of performing one billion billion floating point operations per second. The growing importance of High Performance Computing (HPC) was recently been reaffirmed by the signing of a declaration in support of next-generation computing and data infrastructures by Ministers from nine European countries (France, Germany, Italy, Luxembourg, the Netherlands, Portugal, Spain, Belgium and Slovenia). The organisations participating in EuroEXA ensure a rich contribution in terms of application areas, including climate, meteorology, basic physics, energy, life sciences and bioinformatics. The ultimate goal, which will be the subject of a subsequent EU funding phase, is to implement by 2022/23 an integrated high-performance computing infrastructure at the ExaFlops scale, based primarily on European technology, an ExaScale computing infrastructure available across the EU for scientific communities, industry and the public sector. ■

SCIENTIFIC CULTURE DISSEMINATION

ENRICO FERMI, AN EXHIBITION DEDICATED TO THE GREAT ITALIAN SCIENTIST INAUGURATED IN WASHINGTON

On 2 October, an exhibition dedicated to the famous Italian physicist Enrico Fermi was inaugurated at the Italian Embassy in Washington. The exhibition was inaugurated on the 75th anniversary of Fermi's first self-powered nuclear chain reaction at the University of Chicago. It is organised by the Scientific Office of the Italian Embassy and by the Italian Cultural Institute in Washington and promoted by INFN and the Italian Space Agency (ASI), in collaboration with the Domus Galilaeana foundation, the physics history museum of La Sapienza University of Rome, the American National Gallery of Art, Fermilab and the Fermi Centre.

The exhibition entitled “Enrico Fermi, the Pope of Physics”, includes some of Fermi's original manuscripts and instruments coming from Italy and from the United States. It is an opportunity to honour the greatest Italian scientist since Galileo's time, renamed by his colleagues "the Pope" because, they said, he was infallible, who changed our world with his studies on the atom, opening the way to innovations in the field of physics and technology.

The initiative will follow the lines of the Galilean celebrations already organised in 2014. Stefano Lami, the Scientific Attaché in Washington, explains: "we want to take the opportunity to present current Italian excellence in research and innovation and the close collaboration between Italy and the United States in the field of physics and development of cutting-edge technologies". ■

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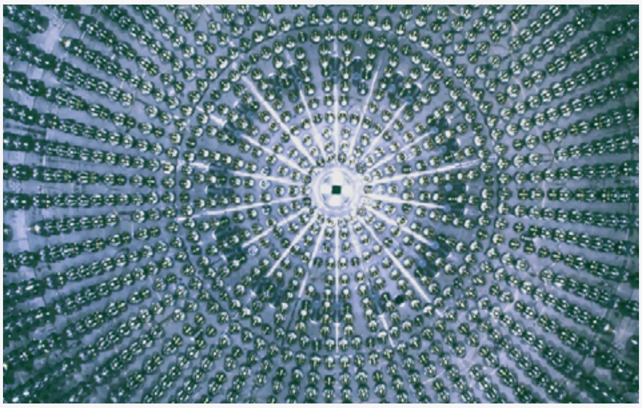

SOX AND THE CHALLENGE OF STERILE NEUTRINOS

SOX (Short distance Oscillations with boreXino) is a project whose scientific objective is to confirm or clearly confute the phenomenon of the so-called "neutrino anomalies" observed by certain experiments worldwide, which have measured an “anomalous” disappearance of some of these particles in neutrino flows. An explanation of the phenomenon might lie in the existence of sterile neutrinos, particles hypothesised based on certain as yet unobserved theories, which differ from the neutrinos we know today due to some of their characteristics: for example, they would appear to interact with matter solely through gravity and not through weak forces.

The SOX project, designed to identify sterile neutrinos, envisages work in tandem of an antineutrino generator and of the Borexino experiment, a highly sensitive neutrino and antineutrino detector in operation since 2007 at INFN's Gran Sasso underground Laboratories, protected from cosmic rays thanks to the 1400 metres of rock of the massif above it. The very high level of radiopurity (i.e. the almost total absence of radioactivity), the large dimensions and the proven ability to measure both neutrinos and antineutrinos with great precision make Borexino the ideal tool to accomplish this research.

The SOX antineutrino generator, which will be manufactured in Russia based on the most up-to-date techniques, will contain a solid powder Cerium-144 source which, spontaneously decaying, will produce the antineutrinos needed for the experiment. The Cerium-144 source will be sealed in a double steel capsule, which in turn will be shielded by a tungsten shield weighing over 2.4 tons and with a thickness of 19 cm, specially made for SOX, in order to prevent the gamma rays, produced together with the neutrinos in the decays, from dispersing outside. The antineutrino generator will then be placed near Borexino, in a housing that will completely eliminate gamma ray emissions, which would irremediably pollute the rare signals left by the neutrinos. The goal of the SOX generator, in fact, is to produce only and exclusively

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antineutrinos, because even the smallest presence of radioactivity would be fatal for the success of the experiment: total isolation of the antineutrino generator from the outside is an indispensable condition for implementation of the project and also of all other research activities in the Gran Sasso underground Laboratories.

Sterile neutrinos. There are three types of neutrinos: electronic, muonic and tau which, when interacting with matter, can produce electrons, muons and tau particles, respectively. However, neutrinos can switch from one type to another: this phenomenon is called neutrino oscillation. Certain neutrino detectors worldwide have observed an anomaly in this oscillation process in electronic neutrino flows, measuring the disappearance of some of these particles. This anomaly can be explained by the existence of so-called sterile neutrinos. The discovery of these particles would have profound implications for the understanding of the universe and of fundamental particle physics. The sterile neutrino would, in fact, open up a new era in physics and cosmology, since it would be the first particle to be discovered not included in the Standard Model, which is our current theory that describes the elementary particles and the interactions that regulate their behaviour. In the event of a negative result, on the other hand, the experiment would be able to definitively close a long debate on the anomalies of the neutrino. Moreover, it could explore the existence of a new physics in low energy neutrino interactions, provide a measurement of the magnetic moment of the neutrino and allow an exceptional calibration of the Borexino detector, very useful for future high-precision measurements of solar neutrinos. ■

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Cover

Artistic representation of the coalescence of two neutron stars.