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THE DISCOVERY OF GRAVITATIONAL WAVES OPENS A NEW WINDOW ON MULTIMESSENGER ASTRONOMY.

Interview with Marco Pallavicini, professor at the University of Genoa and researcher of the Genoa section of the INFN, head of the astro-particle physics committee at INFN.

The two gravitational waves events detected by the LIGO and VIRGO international collaborations in September and December 2015, and respectively announced in February and June this year, not only represent a milestone in the history of the astronomical exploration of the universe, but also unexpectedly reveal a very active Universe in which black hole binary systems are more numerous than we thought. The recent development of new detectors and experimental methods had already allowed multimessenger astronomy - engaged in the coordinated detection of electromagnetic signals, cosmic rays, gamma rays and high energy neutrinos - to observe the universe in its variety and to integrate the results achieved in particle physics, theoretical physics and astronomy within a closely as possible unified framework. Gravitational astronomy, kicked off by the recent discovery of the first gravitational waves, not only adds a piece to this framework, but literally breaks through a barrier in the exploration of the most violent phenomena in the universe. And with the recent success of the LISA Pathfinder (Laser Interferometer Space Antenna Pathfinder) mission, whose goal was to test the technological feasibility of a space observatory for gravitational waves, the future of gravitational astronomy is already evolving. We asked Marco Pallavicini, head of the astroparticle physics committee at INFN, what will the next steps be for this new frontier of multi messenger astronomy.

The first detection of gravitational waves in history has given way to a new field of investigation called gravitational astronomy. We will be able to observe the universe under a new "light"?
It would be more correct to say that we reveal something that we had not ears to "hear". Gravitational waves are generated by physical phenomena that are profoundly different from those that emit photons, cosmic rays or neutrinos - particles with which we have studied the cosmos up to now. Electromagnetic radiation and particle messengers mainly provide information on the presence of cosmic sources and on the transformations of matter within them: changes that involve precisely the

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emission of radiation and particles. Gravitational waves, instead, provide information on the dynamics of masses in motion, that would otherwise not be observable Those observed by LIGO-VIRGO in particular were emitted during the collision of two black holes in orbit around each other, but in general it is the large masses in quick motion or collapse that emit gravitational waves. These are phenomena that can be studied only through this new "window" on the cosmos.

So the more traditional observation tools in the field of astronomy and astroparticles maintain their full validity but can now count on a new level of information.
The study of gravitational waves will teach us many things, especially on black holes and neutron stars, but perhaps we will learn even more from the joint observation of gravitational waves with other traditional sources. The primary one is certainly electromagnetic radiation, i.e. photons, matter of observation for telescopes in traditional astronomy, but also cosmic rays, caught today by experiments distributed on the surface of the earth or in orbit outside the Earth's atmosphere aboard satellites, and neutrinos, on which the experiments made in the abysses or under the ice of the Antarctic are more recently focusing. Gravitational waves complete and enrich the means available to better understand the universe.
Difficult to say today what we expect to observe in the composition of this puzzle. We will very probably gain new information on black holes, on neutron stars and on gravity in the presence of very intense gravitational fields. However, when you open a new way it is difficult to make predictions. The only easy prediction is that there will be many surprises.

Will the recent success of the LISA PATHFINDER mission further extend the future possibilities of gravitational astronomy?
LISA-PF has proved in a spectacular way that the detection of gravitational waves with a space interferometer in the near future will be possible. The future instrument eLISA will observe waves of a much lower frequency than those measurable by LIGO-VIRGO. This will open up new opportunities in physics, such as the observation of collisions of nuclei of galaxies or the measurement of very distant events in the cosmos and, at the same time, it will allow the observation of the signals, already observed with LIGO-VIRGO, hours or perhaps even days in advance, opening the way for largely more accurate and refined measures. In this way, in addition to detecting signals that would otherwise be undetectable, eLISA could work as a pre-alert for the detectors on the ground and on the satellites in orbit around the Earth, allowing them to prepare the field of revelation of the same event or signals connected to it.

What are the most promising outlooks and future developments of multimessenger observation? And what are the most prominent projects for the INFN?
The INFN is engaged in many experiments of "multi-messenger" observation of the Universe from

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Earth, from space, in underground laboratories and in the depths of the sea. We have instruments or we participate in other projects for the observation of different cosmic messengers, among which: low energy neutrinos, in the Gran Sasso National Laboratories; high energy neutrinos, with experiments in the abysses such as in the KM3NeT underwater observatory off the coast of Portopalo di Capo Passero; high energy photons (from GeV to PeV), with the large gamma ray telescopes such as Magic on the Canary Islands and the international CTA project; charged cosmic rays, reveald in their secondary showers by extended detectors on the terrestrial surface like the Auger in the Argentinian Pampa and in their primary composition by detectors placed outside the Earth's atmosphere, on the International Space Station, like Ams, or on satellites, like Pamela and Fermi; and, finally, gravitational waves, with VIRGO. The joint information of these instruments, and obtained through and others in many laboratories around the world, will provide a new way to study supernovae, neutron stars and black holes. And most importantly, they will tell us things that we cannot even imagine now, because this is what has always happened when fundamentally new technologies are acquired. ■