» INTERVIEW

RIBBON CUTTING FOR ADVANCED VIRGO

Interview with Giovanni Losurdo, INFN researcher and coordinator of the Advanced Virgo project

The opening ceremony of Advanced Virgo, the European second generation interferometer for gravitational waves, took place on 20 February at the European Gravitational Observatory (EGO), in Cascina, in the countryside around Pisa, in the presence of members of Virgo and LIGO collaborations and of the institutional representatives of the countries involved. Advanced Virgo has completed the construction phase and has entered the tuning-up phase, in which it is calibrating and tuning all its instruments. It will thus join the two American Advanced LIGO interferometers in the study of gravitational waves, whose discovery was announced on 11 February 2016 by the two LIGO and Virgo scientific collaborations. We talked about Advanced Virgo with the project coordinator, Giovanni Losurdo, to understand how the instrument has been upgraded and what are the prospects now open for the study of the waves.

We cut the ribbon of Advanced Virgo a few days ago. Which interventions were performed on the detector to increase its sensitivity?

It was a substantial upgrade package that involved all parts of Virgo. Starting from the optical design itself: we added an optical cavity (signal recycling an optical method that allows the interferometer response to be optimized). We enlarged the size of the beams in order to reduce the impact of the thermal noise of the mirrors. The mirrors are larger and the surface quality is much improved compared to Virgo. The laser will be more powerful. And to mitigate potential aberrations induced by the higher power we have a very sophisticated thermal compensation system. The super-attenuators, which allowed Virgo to be the most sensitive detector in the world in the low frequency region, have been modified to suspend the new mirrors and other components. A major investment was made to reduce the risk of diffused light, introducing absorber diaphragms and acoustically and seismically isolating all the photodiodes. We improved the vacuum system by introducing cryogenic connections at the extremities of the pipes inside the 3 km long arms of the interferometer. And we also made important

» INTERVIEW

infrastructural interventions, transforming certain laboratories into clean rooms and extending their area in order to be ready for further upgrades of the detector.

The implementation of such complex scientific and technological projects often hides pitfalls. What were the difficulties you encountered in developing Advanced Virgo?
Advanced Virgo is a complex machine. It took 5 years of work to build it. Encountering obstacles along the way is inevitable. We encountered several but there were two main ones. Firstfly, the discovery that some of the special steel blades used in the super-attenuators since the birth of Virgo were broken: we understood the problem, called "hydrogen embrittlement", and we decided to replace a large number of blades to minimize the risk of new breakages. Secondly, the repeated breakage of the fused silica fibres which suspend the mirrors (technology already used successfully during the last run of Virgo, in 2011). After several months of investigation, we understood the cause of the breakage of the fused silica fibres. It was the effect of a contamination caused in a number of vacuum pumps that produced dust: this, accelerated by the pressure gradient during the venting phase (operation during which air is introduced into the vacuum chamber), collided with the fibres and damaged them. So the technology of monolithic suspensions, which Virgo had already successfully used, proved to be valid also in the subsequent evolution engineered for Advanced Virgo. All the problems encountered have been resolved, thanks to the hard work, perseverance and professionalism of the teams involved.

What is the sensitivity now achieved by Advanced Virgo?
At the moment, the mirrors are suspended by steel wires, which increase the noise in the low frequency area. We made this choice because our priority was to start data acquisition with LIGO as soon as possible, but we are ready to reinstate the monolithic suspensions and thus restore the design configuration, as soon as the planning of the data acquisition periods (runs) allows us to do so. Nevertheless, also in the current configuration, Virgo can achieve sufficient sensitivity to detect a coalescence of neutron stars at distances of up to 45 megaparsec (the two LIGOs at the moment are at approx. 80 megaparsec) and make a significant contribution to network aiming.

What was the investment to implement Advanced Virgo?
The Virgo interferometer acquired data until 2011 before being dismantled. This last data acquisition was a great success because we went beyond the sensitivity objective that we promised to achieve when Virgo was first implemented. We also obtained results of great astrophysical significance, such as that on the structure of the Vela pulsar.
In parallel, in 2009, the Advanced Virgo project was approved with a budget of 23.8 million euros: 21.8 million divided equally between INFN and CNRS, the rest as a contribution in kind by

» INTERVIEW

Nikhef. The machine's design work had begun years earlier (the conceptual design dates back to 2007). Starting in November 2008, we went through a review by an international commission led by the American physicist Barry Barish, one of the fathers of the LIGO interferometers. The review process lasted eight months and ended in May 2009 with the recommendation to proceed with its implementation. Construction began in 2012 and ended in the summer of 2016. We are very satisfied with the work done, also because the project was completed within the budgeted cost, and we kept up with the American collaboration: the elapsed time between approval of the funding and the end of the construction work was the same for Advanced Virgo and Advanced LIGO.

What is the planning of Virgo for the future?
I would distinguish three phases. In the short term, the first objective, the top priority, is to conclude the commissioning of the machine, reaching the sensitivity to start data acquisition. The second, at the end of the first run, is to reinstate the monolithic suspension, further increase sensitivity and participate in run O3 with LIGO. Finally, at the end of run O3, we will implement signal recycling and the high-power laser, already envisaged in the Advanced Virgo project for 2018. Furthermore, we have already developed an upgrade plan to further improve the sensitivity of the detector, starting from the installation of a squeezer, a system that reduces the shot noise (the uncertainty in the photons cuinting), which limits the sensitivity of the interferometers at high frequencies. On this, a valuable collaboration with the Albert Einstein Institute in Hanover has begun, which has made available to Virgo the most effective squeezer ever built to date.

The discovery of gravitational waves has pioneered gravitational astronomy and multi-messenger astronomy, that allow us to observe the universe in a new way. What does this mean?
Gravitational waves interact very weakly with matter and can pass through it undisturbed. There are phenomena, such as the collision of two black holes, that we can only observe through gravitational waves. And others, such as supernovae or the coalescence of neutron stars, from which we expect both gravitational waves as well as other types of emissions (electromagnetic, neutrinos). The three interferometers (and those that will join them in the future, such as the Japanese KAGRA), working in conjunction, may be able to locate (as their sensitivity evolves and the number of networked detectors increases) the direction of the signal with greater accuracy. In this way they will provide optical, radio, X and gamma telescopes with aiming indications in order to identify an electromagnetic counterpart of the gravitational signal. This effort is already underway. The LIGO-Virgo collaboration has already signed dozens of memorandums of understanding for the electromagnetic follow up. The simultaneous, multi-messenger observation of these events will open extraordinary prospects for their understanding. And then there's cosmology: fossil radiation

» INTERVIEW

gives us a picture of the universe 380,000 years after the big bang, at an energy scale of just a fraction of an eV. Detection of the cosmological background of gravitational waves would give us a picture of the universe at Planck time, at an energy scale of 10^{19} GeV.

Virgo is managed by the European Gravitational Observatory (EGO) which, established at the initiative of INFN and CNRS, over the years has managed to attract institutes from other countries.
Virgo was founded by Italy and France and has grown, extending to the Netherlands, Poland, Hungary and Spain. EGO is an Italo-French consortium which has included the Netherlands as an observer member. A process of gradual expansion is therefore in progress. But both Virgo and EGO need to grow further in order to remain competitive compared to the size of the LIGO scientific collaboration and the resources invested in the American interferometers: the R&D program for Advanced LIGO cost over 60 million dollars. It is, therefore, necessary to pursue a policy of expansion, primarily towards other European countries. The first step towards acquiring an international, structured functionality is to present the candidacy of EGO as an ERIC, i.e. to become a European Research Infrastructure Consortium, the legal form established by the European Commission in 2009, which allows easier access to European funds, a natural path for the inclusion of future projects in the European Strategy Forum on Research Infrastructures (ESFRI), a possible subsequent transformation into an international organisation.

Planning in this type of research is crucial because the implementation of such complex projects is a lengthy business. Are you already thinking of the European interferometer of the future?
The discovery of gravitational waves was a monumental event, it opened a new era in the observation of the universe. But it is only the first step of an adventure destined to last decades, which will lead to increasing our knowledge in astrophysics, cosmology and fundamental physics. This requires going from the detection of few events to precision observation, characterised high probability and high signal-to-noise ratio. A program of evolution of the current detectors is necessary, whose performance will soon be limited by the potential of the infrastructure that hosts them. That is why, in the period 2008-2011, the conceptual design of a future European observatory, the Einstein Telescope (ET) was implemented. The underground infrastructure will be capable of hosting third-generation detectors, with a quantum leap in observational capacities. An infrastructure of this level requires lengthy planning and implementation times, of the order of 15 years: in order to maintain leadership in the sector and exploit the observational synergies with LISA space mission, at the end of the next decade, it is essential to immediately start the operational analyses.■