NEW COSMIC MESSENGERS: FIRST JOINT SEARCH FOR GRAVITATIONAL WAVES AND HIGH ENERGY NEUTRINOS

Many of the violent phenomena observed in our Universe are potential emitters of gravitational waves and high energy neutrinos. Both these cosmic messengers, not yet directly observed by conventional astronomy, can travel unimpeded over great distances, carrying information from unseen regions of our Universe. The challenge is to jointly analyze data of these different probes and check the hypothesis of a common origin.

Gravitational waves, predicted by Albert Einstein in 1916, are ripples in the space-time metric which are believed to propagate as a wave at the speed of light. These waves warp spacetime, changing the effective distance between nearby points in a characteristic pattern. Scientists attempt to detect gravitational waves using instruments called interferometers that bounce laser beams along two perpendicular arms. Measuring the interference between the beams allows to sense tiny variations in the arm lengths that may be caused by gravitational waves. LIGO is a network of three such instruments in the USA; one in Livingston, LA (4 km arm length) and two in Hanford, WA (4 km and 2 km arm lengths in 2007). Virgo is a 3 km detector located at the European Gravitational Observatory in Cascina, Italy.

These pictures show the Virgo interferometer (on the left), the LIGO Livingston interferometer (in the center) and an artists' impression of the ANTARES neutrino telescope, which is at a depth of about 2500m in the Mediterranean Sea (on the right).

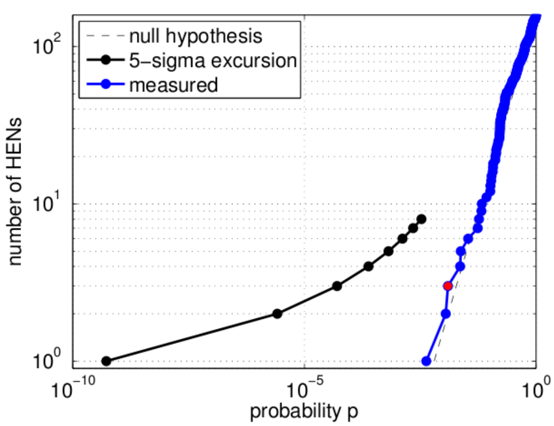
Neutrinos, on the other hand, are common yet enigmatic particles. They are stable, almost massless, and carry no electric charge, interacting with other particles through the weak force. The ANTARES collaboration has built an underwater neutrino telescope at a depth of 2475 m in the Mediterranean Sea to detect high-energy cosmic neutrinos using a three-dimensional array of roughly 900 light detectors (photomultipliers) distributed along 12 lines. Unlike conventional telescopes, ANTARES looks downward, using the Earth to act as a shield, or filter, against all particles except neutrinos (which can easily pass through the Earth). A small fraction of the neutrinos passing upwards through the Earth will interact with the rock in the seabed to produce charged particles called muons, moving at nearly the speed of light. As these muons move through the water, they produce a flash of light called Cherenkov radiation. The photomultipliers detect this light, and from its arrival times the flight direction of the original neutrino can be estimated.

Several known astrophysical sources are expected to produce both gravitational waves and high-energy neutrinos. Soft Gamma Repeaters are X-ray pulsars in our galaxy that exhibit bursts of soft gamma rays ("flares"), which may be associated with star-quakes. The deformation of the star during the outburst could produce gravitational waves, while neutrinos could emerge from the flares. On the extragalactic scale, the most promising sources are gamma-ray bursts (GRBs), which are known to be very energetic. The most popular models for GRBs involve either the collapse of a rapidly rotating massive star or the merger of a binary system of compact objects (two neutron stars, or a neutron star and a black hole). In both scenarios, "jets" of particles moving close to the speed of light are produced that give rise to the observed gamma-ray burst. The presence of protons or other hadrons in the jets would ensure the production of high-energy neutrinos, while gravitational waves would be produced by the binary merger or by any of several plausible mechanisms in the collapsing star scenario.

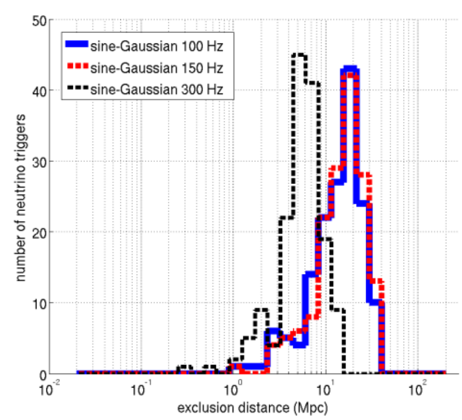
The present analysis combines data from ANTARES, LIGO, and Virgo from 2007 to search for gravitational waves coincident with neutrinos. ANTARES data were used to determine the arrival time and direction of candidate high-energy neutrino events. The LIGO-Virgo data were then scanned for a gravitational wave around the time of each putative neutrino. The ANTARES Collaboration has selected 216 potential neutrino events (this number being compatible with the expected background induced by cosmic ray interactions with the atmosphere). The neutrino track is reconstructed by using the time and charge of the hits on the photomultipliers. The subsequent LIGO-Virgo analysis exploits our knowledge of the time and possible directions of the neutrino event to improve the search sensitivity, allowing the detection of weaker gravitational-wave signals than would be possible without the neutrino information. We found no coincidences between a gravitational signal and a neutrino candidate. In addition, a statistical analysis of the gravitational-wave data for all neutrino candidates together showed no evidence for a weak collective signal (first figure at right). That means that if any any of the neutrino candidates came from the astrophysical sources being considered, they must have been too far away for the gravitational waves to be detectable. Simulations based on models of the maximum expected gravitational-wave emission from collapsing stars indicate that such sources would have to have been at least ~10 megaparsecs (33 million light years) away from the Earth (second figure at right). The LIGO and Virgo detectors are currently being upgraded to be able to reach farther into the Universe with future data.

FIGURES FROM THE PUBLICATION

For more information on how these figures were generated and their meaning see the publication at: **http://arxiv.org/abs/1205.3018**.



The distribution of measured probability values (denoted by the blue dots) is consistent with the hypothesis that the potential neutrino events originated from the background expected from cosmic ray interactions with the atmosphere. The most significant deviation from this background hypothesis is indicated by the red dot. However, to imply a detection, one of the blue dots would have to lie to the left of the line composed of black dots.



These histograms show the distances to which the analysis would be sensitive to different classes of signal. 1 Mpc = 10^6 parsec and 1 parsec = 3.3 light years.

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Freely readable preprint of the paper describing the analysis and results: http://arxiv.org/abs/1205.3018

Webpage with data used to make the plots and tables in the paper:
https://dcc.ligo.org/cgi-bin/DocDB/ShowDocument?docid=p1200006

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