

X-RAYS AND GRAVITATIONAL WAVES: LIGO AND VIRGO POINT THE WAY FOR THE SWIFT SATELLITE

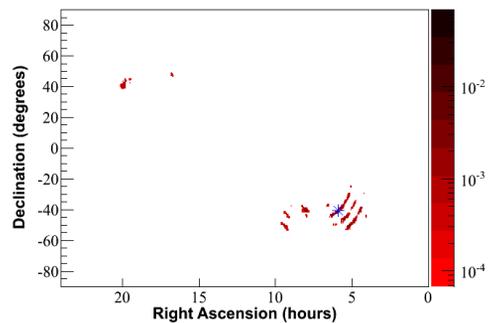
Seeing and hearing something at the same time can teach you more than you could learn with just one sense. In the same way, combining gravitational waves with conventional astronomy done with electromagnetic waves (light, X-rays, radio waves etc.) promises to teach us much more about the universe than either could alone. For years, LIGO and Virgo have looked for gravitational waves specifically at times and locations where astronomers told us a [gamma-ray burst](#) or other interesting event was happening. In 2009 and 2010 LIGO and Virgo created a prototype [electromagnetic follow-up program](#) to send information in the other direction as well, telling astronomers where and when to look for the source of candidate gravitational wave events. A recent [publication](#), written jointly by Swift and LIGO-Virgo scientists, is summarized here. It describes the Swift satellite's first ever search for electromagnetic radiation in X-ray, ultraviolet and optical wavelengths in coincidence with gravitational waves as part of this program.

In addition to a wide field-of-view Burst Alert Telescope that scans the sky for gamma-ray bursts, the [Swift](#) satellite has two instruments with smaller fields of view. These two telescopes can rapidly point towards a location in the sky and determine the location of sources very accurately, making them particularly useful for targets of opportunity like LIGO-Virgo candidate events. Swift's X-ray telescope can see a section of the sky that is about four tenths of a degree on each side and its ultraviolet/optical telescope can see a slightly smaller area.

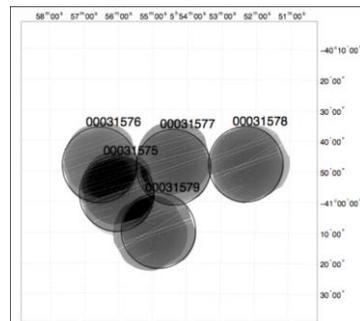
LIGO and Virgo scientists selected two potentially interesting events to send to Swift. One of these occurred in January 2010. The other, occurring in September 2010, was later revealed to be a "[blind injection](#)" artificial test event. Swift looked at 5 sky locations associated with the January event and 2 locations associated with the September event. There were several X-ray detections in images associated with each event, all barely above the noise level. However, there are always sources of X-rays anywhere you look in the sky, and the number, brightness and variability of the observed detections was very consistent with the background one would expect when pointing to these sky locations randomly. The sky is even busier in the optical and ultraviolet bands but, of the nearly 7000 sources that were picked up by Swift's ultraviolet/optical telescope, none showed the kind of variability one would hope to see from an electromagnetic signal associated with a transient gravitational wave. Overall, based on Swift's observations, there was no evidence for an unusual electromagnetic signal in coincidence with either of the selected gravitational wave candidates.

FIGURES FROM THE PUBLICATION

For more information on the meaning of these figures see the preprint at: <http://arxiv.org/abs/1205.1124>.



Map of the sky showing the regions most likely to be the origin of the January event. The blue asterisk shows the region selected for follow-ups with Swift based on the probability distribution.



Sky locations imaged by Swift while following up the January event. This is a close-up of the region marked by an asterisk in the top figure. The x-axis (horizontal) is right ascension in hours, minutes and seconds. The y-axis (vertical) is declination in degrees. The grayscale is proportional to the length of observation at each sky location, with darker sections corresponding to longer exposures.

In addition to following up two actual triggers, a more extensive study was conducted with computer simulations to see how much a corresponding X-ray detection could increase our confidence that we really had detected a gravitational wave. In this study, realistic X-ray signals were combined with simulated gravitational waves originating from nearby galaxies. The results from this hypothetical population of sources were compared with real background distributions. The figure on the bottom right shows the results of the simulation. For reference, some areas of physics consider a 5 sigma false alarm probability, between 10^{-8} and 10^{-7} on the plot, to be an unambiguous detection. It is clear from these simulations that coincident X-ray sources could dramatically increase our confidence in a gravitational wave observation.

These prototype follow-up studies demonstrate the tremendous potential benefits of gravitational wave detectors partnering with astronomical observatories like Swift. Multi-messenger astronomy will only get more interesting in the era of Advanced LIGO and Advanced Virgo.

READ MORE

Freely readable preprint of the paper describing this work:
<http://arxiv.org/abs/1205.1124>

Recent LIGO publication on the origin of GRB051103:
<http://www.ligo.org/science/Publication-GRB051103/>

Recent publication on the LIGO-Virgo E-M follow-up program:
<http://www.ligo.org/science/Publication-S6EMFollowUpMethods/>

Homepage of the Swift mission:
http://www.nasa.gov/mission_pages/swift/main/index.html

Further information on the “Big Dog” blind injection test event:
<http://www.ligo.org/news/blind-injection.php>

GLOSSARY

declination: along with right ascension can be used to define the location of objects on the sky. It is similar to latitude on Earth: a star along the equator is at 0 degrees declination while a star at the north or south pole has a declination of 90 degrees or -90 degrees, respectively.

electromagnetic waves: waves composed of coupled electric and magnetic fields. These waves are commonly known as light, although only a small portion of EM wavelengths can be seen by the human eye. In order of increasing energy, the kinds of EM light include: radio, visible (optical), UV (ultraviolet), X-rays, Gamma-rays.

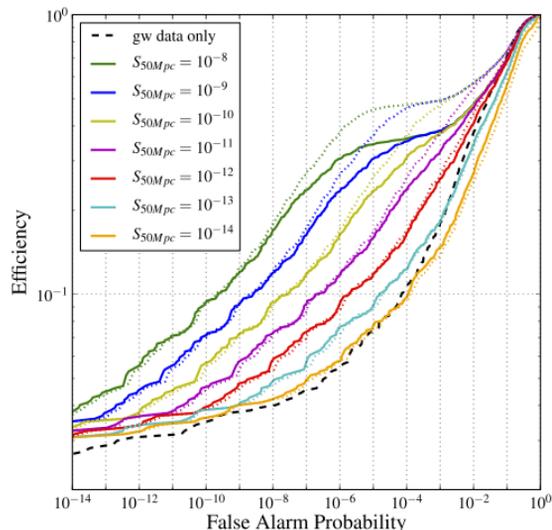
false alarm probability: the probability that a detector noise fluctuation could produce an event similar to a candidate event being considered.

field of view: the size of the region of sky a telescope can see at a given time.

gamma-ray bursts: extremely energetic explosions of gamma-ray light from astrophysical sources very far away. The exact cause of these bursts is not known.

megaparsec: abbreviated Mpc, is a unit of distance. It is one million parsecs, about 3.3 million light years or 3×10^{22} meters.

right ascension: along with declination can be used to define the location of objects on the sky. It is similar to longitude on Earth. It is historically measured in hours, minutes and seconds, because astronomers can use right ascension values to determine at what time a star will become visible above the horizon.



Detection efficiency (i.e. fraction of events detected) versus false alarm probability for combined gravitational wave and X-ray observations. Results are from a simulation using realistic X-ray sources at a distance of 50 megaparsecs (Mpc) from Earth. Comparing the colored lines to the black dashed lines shows how much observing various X-ray sources increases the statistical significance of our observation compared to just a gravitational wave alone. The solid lines show the result if Swift looks at the best 5 sky locations associated with each event and the dotted lines show the result for 10 locations.

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