The AGILE pipeline for Gravitational Waves events follow-up

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Abstract. The first direct detection of gravitational waves (GW) by Advanced LIGO detectors in September 2015 has drawn the attention of the astrophysical community that is now searching for the electromagnetic counterparts of the detected GW events. The AGILE (Astro-Rivelatore Gamma a Immagini Leggero) mission is primarily devoted to the high-energy astrophysical study of gamma-ray sources in the 30 MeV to 30 GeV energy range. The capability of the AGILE satellite for the discovery of transients is unique: the actual spinning configuration of the satellite, together with a large field of view and a good sensitivity of $F = (1 - 2) \times 10^{-8}\ erg\ cm^{-2}\ s^{-1}$ for 100s integrations, provides a coverage of 80% of the sky, with each position exposed for 100 seconds, 200 times a day. The AGILE team signed a memorandum of understanding (MoU) with the LIGO/Virgo collaboration to follow the GW notices provided through the GCN network.

In this paper we describe our automated pipeline that reacts to LIGO/Virgo GW notices and performs different kind of automated analysis to boost the search for of GW event counterparts.

1. Introduction

During September 2015 the Advanced LIGO interferometers detected the first signal of a gravitational wave starting a new era for astrophysics. The GW-emitting source GW150914 (Abbott et al. 2016) that has been discovered concern the final stage of coalescence of two black holes and is the first direct observation of a binary black hole merger. The capabilities of LIGO to observe the coalescence of binary systems, involving black-holes (BHs) and neutron stars (NS), has attracted the astrophysical community which is looking for the discovery of their electromagnetic counterpart. AGILE is an X-ray and gamma-ray telescope (Tavani et al. 2009) which has unique capabilities for the discovery of GW EM counterparts (Tavani et al. 2016): the satellite is currently operating in low-earth orbit in spinning mode covering a large portion of the sky up to the 80% every 7 minutes and can detect gamma-ray transients (Marisaldi et al. 2009) that last less than a millisecond long up to hundred of seconds. AGILE has a wide field of view of $2.5sr$ and with 200 pass a day for each accessible sky regions looks promising for the GW follow-up. The AGILE team signed an MoU to collaborate with the LIGO/Virgo collaboration, which allows us to receive LIGO/Virgo notices. We created a new gravitational wave pipeline for the automated analysis of gravitational wave events EM counterparts.

2. Gravitational Wave pipeline

This work describes the AGILE pipeline for the discovery of gravitational waves (hereafter, GW) EM counterparts follow-up. The design of the pipeline is based on the (AGILE Alert System for Gamma-Ray Transients Bulgarelli et al. 2014)). The goal of the pipeline is to minimize the reaction time for the follow-up of GW events. When a new notice from LIGO is received the pipeline performs automatically the preconfigured analysis, providing a quick look of the gamma-ray sky during the GW event. Then, the GW advocates on duty can study the results of the elaboration of the pipeline and perform their refined analysis. In case of a GW event counterpart detection an alert is sent to the LIGO/Virgo community. A procedure has been established to coordinate the work of the GW advocates and to minimize the time required to perform all these steps. The GW pipeline improves the responsiveness of the procedure using automation when it is possible.

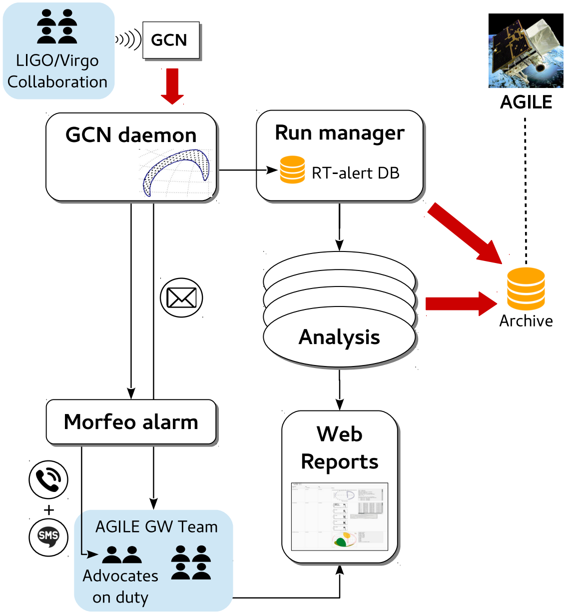


Figure 1. When a GW event occurs LIGO triggers an alert to the GCN. The GCN daemon receives the alert, stores it in the RT-Alert Database, informs via mail the GW team and starts the Morfeo alarm, which calls the GW advocates on duty. A brief web report is given to them. When the AGILE data for the event is available in the archive, the Run manager starts the configured analysis and then the detailed results pages are accessible.

The GW pipeline (Figure.1) is composed of five components. Follows a detail of each component.

The GCN daemon (written in C) is the GW pipeline interface to the NASA GCN which provides the LIGO LVC notices. The daemon has additional functionalities and acts as a controller for the pipeline. When a new notice arrives the daemon performs the following steps:

- parsing the LIGO notices received as Virtual Observatory Event (VOEvent) v1 and v2 formats,
- extracting the contour required for the following automated analysis,
- inserting the notices informations into the RT-Alert Database system,
- pushing the notice in the Morfeo alarm queue which then can start an alarm,
- and send an alert to the AGILE GW team via e-mail providing a brief description of the event ongoing and the links to the Web Reports.

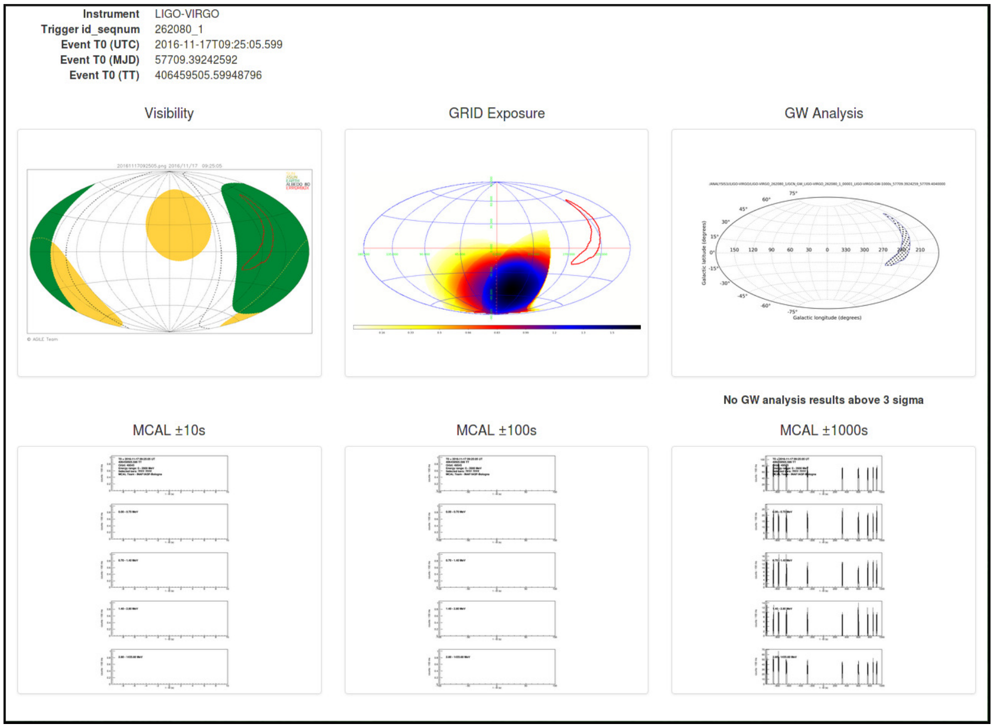
The Run manager component handles the execution of the analysis through a job scheduling system. To keep track of the runs it uses the RT-Alert Database, which also holds the configuration parameters for the automated analysis to be performed. As we reported before the database is is used also for the archiving of the LIGO alerts and the their associated error boxes. The RT-database is then a single flexible solution that allows us to add new analysis, reconfiguration and re-run them, or the injection of alerts with a simple query on the database. This is possible because there is a direct association between the Run manager scheduling logic and the RT-Alert database by means of the Analysis Type Identifier.

The Analysis currently configured are (1) the GRID Maximum Likelihood Method for Detecting Short-Term Variability of AGILE gamma-ray Sources (Bulgarelli et al. 2012) , (2) the MCAL GRB analysis (Marisaldi et al. 2009) and (3) a dedicated GW analysis which scans the LIGO error region and performs a significance estimation (Li & Ma 1983) on multiple sky coordinates.

The results of the analysis is then collected and shown into different Web Reports (see the Figure.2). Providing useful informations and keeping them at minimum is a tricky task for the automated systems. We performed an iterative development/testing process with the AGILE developers and scientist to identify the useful data and how to show them. The usability of the Web Reports is also important. We opted for a specific responsive grid layout which adapt the pages contents to any kind of device display. The presentation logic is performed completely client-side (the browser) using JavaScript code and libraries using the web server only to retrieve the data to display.

The Morfeo alarm is a telephone alarm that wakes up the AGILE GW advocates on duty. When a new notices arrives it sends an SMS to the advocates and begins to make telephone calls via a dedicated VoIP service to each advocate on duty until someone dismisses the alarm. With this system we can reach the same advocate reactivity of working day during the night time and non-working days. The costs of the system are negligible because the calls are closed in both cases of advocate answer or not.

To test the GW pipeline we used the LIGO test notices and we injected some GRBs detected by AGILE. With the capability to perform injection it has been possible to test the advocates reactivity and the proper functioning of all the subsystems.



Instrument	LIGO-VIRGO
Trigger id_seqnum	262080_1
Event T0 (UTC)	2016-11-17T09:25:05.599
Event T0 (MJD)	57709.39242592
Event T0 (TT)	406459505.59948796

No GW analysis results above 3 sigma

Figure 2. A Web Report showing analysis results of a LIGO test event on prompt. The visibility image shows the error region of the LIGO event (red) over the earth occultation (green), the GRID exposure is far from the error region (red), the GW analysis subsequently shows no results scanning within the error region (blue) and the MCAL plots light curves shows there were no triggers around the event T0.

3. Conclusions

AGILE has great capabilities for the discovery of the gravitational wave EM counterparts. We have built a GW pipeline for their automatic follow-up with the purpose of being reactive and perform a set of pre-configured analysis. At the moment, the pipeline is stable and ready for the next LIGO O2 observation run. A lot of work on the pipeline is still in progress, from the addition of new analysis and their visualization to the configuration of backup servers to be completely fault tolerant.

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