The AGILE Science Alert System

M. TRIFOGLIO, A. BULGARELLI, F. GIANOTTI, F. FUSCHINO, M. MARISALDI, M. TAVANI, E. DEL MONTE, Y. EVANGELISTA, F. LAZZAROTTO, S. SABATINI, F. LONGO, E. MORETTI, C. PITTORI, F. VERRECCHIA
ON BEHALF OF THE AGILE TEAM

1. Introduction

The AGILE Mission (Tavani et al. 2009), dedicated to high-energy astrophysics, is designed to detect and image photons in the 30 MeV-50 GeV and 15-45 keV energy bands. The Payload complement consists of the Gamma-Ray Imaging Detector (GRID), with a large field of view, optimal time resolution and good sensitivity, combined with the hard X-ray monitor, Super-AGILE (SA), and the CsI(Tl) Mini-Calorimeter (MCAL). AGILE was successfully launched on 23 April 2007, and during the first two years of operations it performed observations with fixed pointings, called Observation Blocks (OB), of typical duration of ~2 weeks. Due to a ~550 km equatorial orbit with inclination angle ~ 2.5°, AGILE data are down-linked every ~ 100 minutes to the ASI Malindi ground station. From Malindi, the data are relayed through the ASI multi-mission network infrastructure (ASINet) to the Satellite Control Centre at Fucino, and then to the ASI Science Data Center (ASDC) at Frascati which hosts the AGILE Data Center (ADC) 1. At each downlink, the AGILE raw TM received at ADC is automatically archived and transformed in FITS format (LV1) through the AGILE Pre-Processing System (TMPPS) (Trifoglio et al. 2008). All AGILE-GRID LV1 data are routinely processed using the scientific data reduction and analysis software tasks developed by the AGILE instrument teams and integrated into the Quick Look (QL) and standard analysis pipelines developed at ADC (Pittori et al. 2010).

AGILE is well suited for detection and alerts on γ-ray galactic and extra galactic transients, γ-ray bursts (GRB), X-ray bursts and other transients in the hard X-rays. Both the mentioned QL pipelines running at ADC and the AGILE Science Alert System developed and running at the AGILE Team Quick Look sites have been designed to automate the identification of these astrophysical events in the AGILE data. In the following we present in particular the Alert System architecture and performances.

2. Alert System architecture and performances

As sketched in Figure 1, the Alert System consists of several tasks running at the AGILE Team Quick Look sites. The 3 Alert Pipelines (SA, GRID, MCAL) process the LV1 data

1 http://agile.asdc.asi.it
as soon as they are received from ADC within \( \sim 40 \) minutes after the TM down-link start \((T_0)\) at the Ground Station, together with the auxiliary data (AUX) required for the AGILE orbit and attitude reconstruction.

The SA Alert Pipeline runs at IASF Roma to search for GRB, X-ray bursts and other transients in the hard X-ray band. The GRID Alert Pipeline and the MCAL Alert Pipeline run at IASF Bologna. The former is devoted to detection and alerts on galactic and extra galactic transients in the Field of View (FOV) of the GRID detector. The latter processes the data of the MCAL burst chain in order to identify burst on-board triggers and to search for both Cosmic GRB and for valid Terrestrial Gamma-ray Flashes (TGF) candidates. Each Pipeline, in case of transient or burst detection, alerts the AGILE team via e-mail and via SMS to mobile phones.

In addition, at IASF Bologna the Dispatcher task handles the Swift/BAT, INTEGRAL/IBIS, and Fermi/GBM Notices received from the GRB Coordinates Network (GCN) through a TCP/IP Internet socket and the GRB alerts generated via e-mail by the above SA and MCAL Pipelines. In case the GRB is localized inside the GRID Field of view (FoV), this task runs the GRID GRB Analysis Pipeline in order to search for a detection or provide an upper limit (UL) on the flux. The analysis results are e-mailed
Alert System performance measurements have been collected over a period of 400 orbits in September 2009. They show that the time taken by the Alert System Pipelines to process the LV1 data of each orbit and generate the alert, if any, varies from $\sim 4$-5 minutes, in the SA and MCAL cases, to $\sim 38$-74 minutes, in the GRID case. Hence, the time elapsed after $T_0$ is $\sim 44$-45 minutes and $\sim 78$-114 minutes, respectively.

The Quick Look data products (e.g.: maps, light curves, spectra) are made available to the Team through Web pages. Local and remote access to the interactive analysis tools available at ADC and at Agile Team sites allow the Team to perform further analysis of the alert. This has led to the issue of ATels within $T_0 + \sim 0.5$-1 day for both SA and GRID, and to the issue of GCNs within $T_0 + \sim 1$-3 hours for SA and MCAL, and $T_0 + \sim 12$ hours for GRID. Further details on the main Alert System components are given hereafter.

### 2.1. SA Alert Pipeline

The SuperAGILE ground software (Feroci et al. 2007) is equipped with a trigger algorithm in order to search for GRB, X-ray bursts and other transients in the hard X-ray band. The ground trigger runs on timescales from 512 ms up to 16384 ms using the Scientific Ratemeters telemetry data and taking advantage of the segmentation of the SuperAGILE detector. Up to now, the SuperAGILE ground trigger has detected several GRBs and X-ray bursts, including the remarkable flare from IGR J17473-2721 A remarkable flare from IGR J17473-2721 (26 March 2008) heralding the reactivation of the source and allowing its classification as Low Mass X-ray Binary.

### 2.2. GRID Alert Pipeline

This is an updated version of the AGILE GRID Science Monitoring system (Bulgarelli et al. 2009). It consists of three main stages: (a) event filtering, which applies the software modules of the AGILE standard analysis (Vercellone et al. 2006) to reconstruct the event characteristics and filter out the background events, (b) map generation, which executes the software modules of the AGILE scientific analysis (Chen et al. 2009) to build maps of the last 24 hours of GRID observation, and (c) transient search to check for the presence of galactic or extra-galactic transients in the FoV of the GRID detector.

In the current version the search for candidate transient Galactic sources in daily AGILE GRID maps is carried out with two statistical methods: (i) blind-search (SPOT4) based on counts excesses search and on the likelihood multi-source analysis; (ii) rate of false discoveries (FDR) in source detection, that selects candidate sources with a FDR of $10^{-3}$. The former uses as input the maps having FoV of 100°. As first step (SpotFinder), it extracts from the intensity map the list of the more intensive spots. Hence, it applies on these spots the likelihood multi-source analysis method. The remaining operations are performed as in the previous mentioned version. FDR is a new functionality that allows to control the rate of false discoveries (FDR) in source detection (Sabatini et al. 2010). The search is performed on counts maps and it is based on the idea that the flux from a source stands on top of the background emission and it is therefore expected to be on average higher than the background flux. We can then define a threshold above which counts values have a 'low probability' to be statistical fluctuations of the background and are therefore likely to be part of a source. In the use of this thresholding technique the crucial point is the definition of the threshold value, that one wants to be high enough to minimize the contamination by false detections and low enough to select the higher possible number of sources. The contamination and the completeness of the selected sample of sources can be assessed statistically based on the used threshold value. The FDR method allows to define the threshold based on the set of data and controls the false discovery rate in the case of multiple testing. We developed an automatic analysis
of the daily maps of AGILE GRID that performs the FDR, selects candidate sources with a false discovery rate of $10^{-3}$ and sends an alert to the AGILE team.

2.3. MCAL Alert Pipeline

This is an updated version of the MCAL burst monitoring pipeline presented in Bulgarelli et al. 2008. For every trigger detected by the on-board logic the event data are analyzed to exclude instrumental triggers. All valid bursts are then analyzed to extract automatically the main physical parameters (T90, fluency, peak flux). In 4-5 minutes the analysis completes, and the results as well as the light curve in different energy bands are sent to the Team by e-mail. In addition a suitable e-mail is sent to the Dispatcher in order to perform the burst search in the GRID (see 2.4). Triggers on very short (<16ms) time scales are analyzed using different criteria to search for both Cosmic GRB and for valid Terrestrial Gamma-ray Flashes (TGF) candidates. Information on good TGF candidates are notified automatically to Agile Team and external collaborators for rapid correlation with atmospheric (Very-Low Frequency - sferics ) data. Information on all on-board triggers are stored in a database that can be accessed from the WEB for monitoring. In addition, on contact by contact basis, a ground trigger algorithm runs on scientific ratemeters to notify via e-mail the MCAL team for transients not recognized by the on-board logic.

2.4. GRID GRB Analysis Pipeline

As mentioned above, an Alert System task handles the Notices received from the GCN. For each Notice, it waits the AGILE telemetry to estimate the visibility of the burst position at the trigger time. In case the GRB is localized inside the GRID FoV, it sends, through the Dispatcher, the burst information (time start, RA, DEC) to the Pipeline. A map showing the GRB direction and the AGILE pointing is produced and mailed to the Team. The same run modality (i.e. with coordinates ) applies for the e-mails generated by the SA Alert Pipeline. The GRID GRB Analysis Pipeline performs the GRB search in the AGILE data by comparing the expected background with the counts in the first 60s in a region of 15° of radius centered at the position of the burst. The method used to estimate the detection and the UL (Moretti et al. 2009) is based on the derivation of the Bayes theorem. A good estimation of the background is required to use this approach, to know with negligible error the mean background rate. The background mean is calculated in a time interval at least 10 times longer the duration of burst and before the trigger. During this time interval both background and signal are supposed to follow a Poisson distribution and the signal to be non-negative.

References

Bulgarelli A. et al. 2008, NSS '08 IEEE 19-25 Oct. 2008, 2153, 2158
Bulgarelli A. et al. 2009 ASP Conference Series, 411, 362, 365
Chen A. et al. 2009, GRID Scientific Analysis User Manual, AGILE-IFC-OP-009
Feroci M. et al. 2007, NIMA, 581, 728-754
Moretti E. et al., 2009 Italian Physical Society, submitted
Pittori C. et al., 2010, in preparation
Sabatini S. et al. 2010, A&A, submitted
Tavani M., et al 2009, Astron. Astrophys. 502, 995,1013
Vercellone S. et al. 2006, Correction and Standard Analysis, AGILE-IFC-OP-010
Trifoglio M. et al, 2008 Proc. SPIE, 7011, 70113E-1