Fast and Super-Fast Analysis of AGILE Gamma-Ray Transients

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ABSTRACT

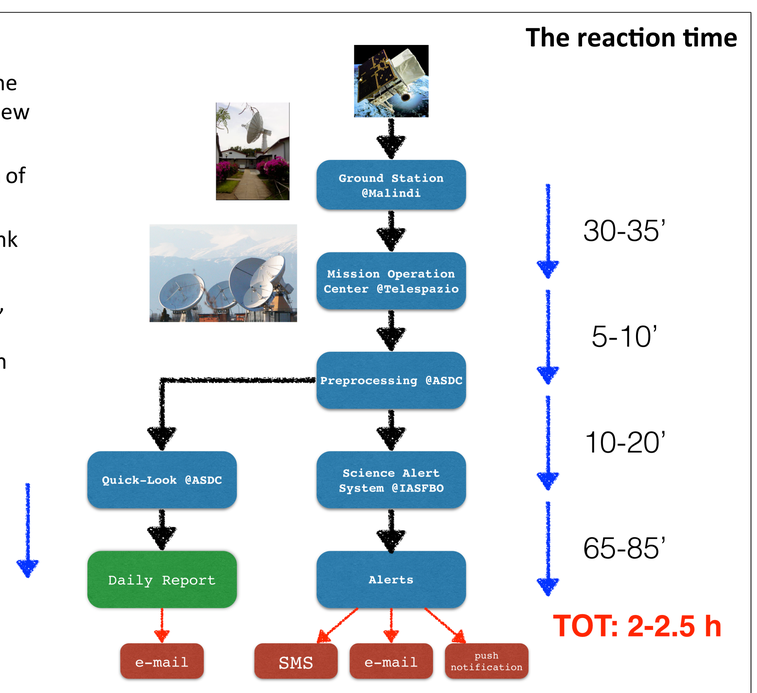
In this poster we focus on the scientific operations of the Gamma-Ray Imaging Detector (GRID) on board the AGILE space mission. This work presents the AGILE innovative approach to fast γ-ray transient detection, which is a challenging task and a crucial part of the AGILE scientific program. The goals are to describe (1) the AGILE Gamma-Ray Alert System, (2) a new algorithm for blind search identification of transients within a short processing time, (3) the AGILE procedure for γ -ray transient alert management, and (4) the likelihood of ratio tests that are necessary to evaluate the post-trial statistical significance of the results. Special algorithms and an optimized sequence of tasks are necessary to reach our goal. The system is capable of generating alerts within two to three hours of a data downlink, an unprecedented reaction time in γ-ray astrophysics.

The procedure

- Transient discoveries from gamma-ray sources during the AGILE observations is possible given the large Field of View and the AGILE sensitivity
- A quick reaction time enables us to follow the evolution of a flaring event
- Data are automatically analyzed at every orbital downlink by an alert pipeline operating on different timescales.
- As proper flux and significance thresholds are exceeded, alerts are automatically generated and sent as SMS messages to cellular telephones, via e-mail, and via push notifications from an application for smartphones and tablets.
- These alerts are crosschecked with the results of two pipelines, and a manual analysis is performed.
  - Science Alert System @ INAF/IASF Bologna
  - Quick-Look System @ ASI/ASDC

QLS@ADC	*SAS@IASFBO*
It performs an accurate data processing	*It performs a raw data processing*
It generates daily REPORTS	*It generates ALERTS immediatly*
	It works with a continuous integration of data: the data are analyzed for each orbit

The reaction time



The most innovative aspects (1): a technological point of view

A. Fast **data transfer** between Ground Segment components (from Kenia to Bologna): 45-65'

B. Fast **background filtering** (FM3.119) and **scientific analysis** software: binning Maximum Likelihood Estimator

C. New algorithm that extracts "candidate flare" from the gamma-ray sky: ***spotfinder***

D. Alert generation with different methods

65-85 min : B., C., D.

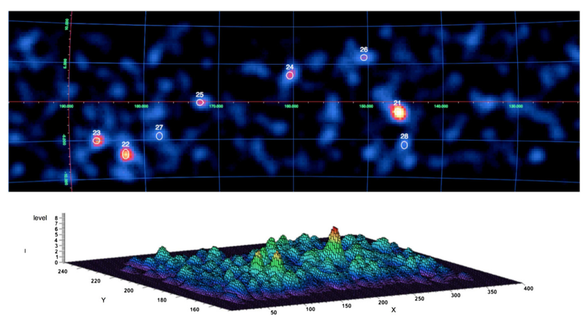


Figure: spotfinder algorithm for the extraction of connected regions into a multilevel γ-ray map. Top panel: a region of the Galactic plane used as an example; also shown in the same picture are the connected component regions identified by spotfinder. Second panel: the same sky region normalized in eight levels.

The most innovative aspects (2): a statistical point of view

- The automated procedure that analyzes the gamma-ray sky at each AGILE orbit (96') implies a sliding window offset by one orbit. This means that the 15 maps analyzed each day by the system are not independent of one another.
- Evaluation of significance of a detection and new simulations in this

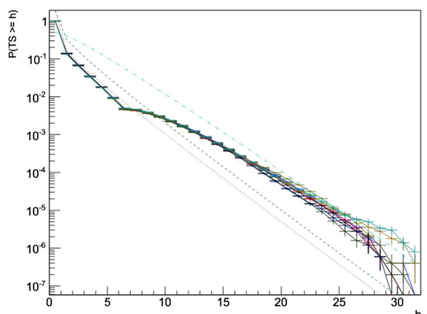


Figure: Histograms are the p-value distributions for an empty Galactic region when there are eight sources in the ensemble of models. The flux and position of the sources are left free; ggal and giso parameters are free. The red dotted line is the (1/2) χ_1^2 theoretical distribution, the green dashed line is the χ_1^2 theoretical distribution, the cyan dot–dashed line is the (1/2)χ_3^2 distribution.

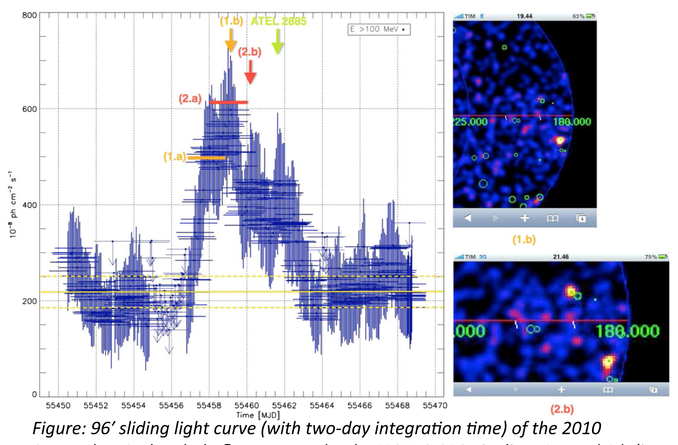
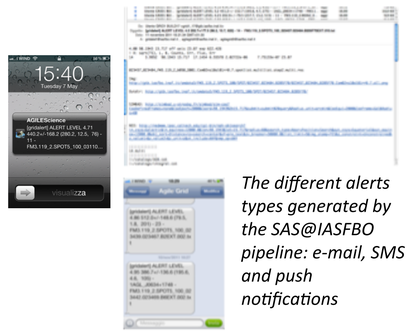


Figure: 96' sliding light curve (with two-day integration time) of the 2010 September Crab nebula flare as seen by the IASFBO SAS pipeline. 1.a and 1.b (in orange) are, respectively, the detected flux and the time of the alert generation by the IASFBO SAS pipeline when Crab nebula reaches a flux level that exceeds 1σ the mean flux level; on the right are the counts map of 1.b. 2.a and 2.b (in red) are related to the maximum flux level reached; on the right are the counts map of 2.b. The green arrow indicates the time that the Astronomical Telegram was posted.

The most innovative aspects (3): the manual management of alerts

- When an alert from SAS@IASFBO is received and a proper flux and significance thresholds are exceeded a manual analysis starts.
- Two pipelines:
  - SAS@IASFBO for fast data analysis
  - QL@ADC for high quality data processing
- Two groups for two independent checks on two data set
- We can start the manual analysis with a raw archive when the alert is received and perform a refined check when the QL@ADC data is available

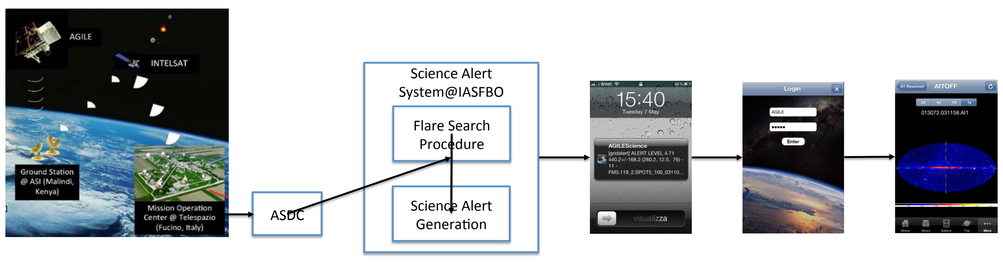
The ASDC daily report generated by QLS



The different alerts types generated by the SAS@IASFBO pipeline: e-mail, SMS and push notifications

The most innovative aspects (4): towards a super-fast reaction

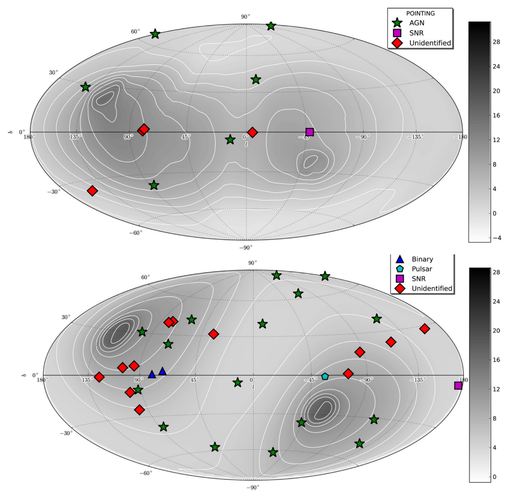
The App for mobile devices is deeply integrated into a scientific ground segment, and it is used for daily scientific activities. The application takes information from two databases that receive data from the AGILE Science Alert System developed at IASFBO.



When an automatic candidate alert is received through the notification system, the private section of the app can be used to access the AGILE-GRID maps to check the automated results. This means that access to the gamma-ray data is really fast.

The most relevant results

1. The first detection of transient γ -ray emission from Cygnus X-3 in the energy range of 100 MeV–50 GeV (Tavani et al. 2008), which was confirmed by the Fermi/LAT collaboration (Abdo et al. 2009b) and reported in Tavani et al. (2009b), Bulgarelli et al. (2012b), and Piano et al. (2012).
2. The discovery of γ -ray flares from the Crab Nebula in 2010 September (Tavani et al. 2010) (confirmed by Fermi-LAT within 1 day; see Buehler et al. 2010). The first detection of a Crab Nebula flare was made in 2007 September by the IASFBO SAS pipeline.
3. The first ATel that alerted the astrophysical community of the extraordinary activity of the blazar 3C454.3 in 2010 December, which was in addition to the detection, early in the mission (2007) and at a later stage (2009 and 2010), of very bright gamma-ray emission (Vercellone et al. 2010, 2011).
4. The detection of many gamma-ray flares from blazars.



Position and classification of the published AGILE/GRID Astronomical Telegrams in "pointing" and "spinning" mode overlapped to the exposure map

Conclusion

In this work we described the main features of the fast gamma-ray data processing of the AGILE mission. In particular, we focused on the "spotfinder" algorithm, the optimization of software tools, the data link from the satellite to data processing centers, the orbit-by-orbit data analysis, and the statistical characterization of the data analysis system. An important part of the data processing is the extensive use of mobile technologies coupled with the simultaneous implementation of two independent pipelines of the AGILE Alert System. Identifying unexpected transient astrophysical events within a very short time is of crucial importance for high-energy astrophysics. The AGILE Alert System has demonstrated to be quite successful in source detection and rapid alert capability. The AGILE mission and the scientific community have certainly benefited from its implementation, which maximizes the scientific return of γ-ray observations.

References

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[4] Pittori, C. NuPhS, 239, 104, 2013
[5] Parmiggiani et al. this poster session