WP 12. Multi-messenger Astronomy exploitation and tools

TASK 12.2 Prompt High Energy emission, Deliverable No. 1

Title

"AFIS PLATFORM PROTOTYPE"

Project acronym:
AHEAD2020

Project Title:
Integrated Activities for the High Energy Astrophysics Domain

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2020-03-02

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File Name: AFIS Platform Prototype
Prepared by: Nicolò Parmiggiani

Version	Revision Date	Prepared by	Review and approval
1.0	23-03-2023	N. Parmiggiani	A. Bulgarelli A. Bazzano M. Branchesi

Distribution List	Date	Version

1. Introduction

The rapid detection of high-energy transients by multi high-energy satellites represent a key step to increase the significance of the high-energy candidate events, to improve their localization, and to cover the source spectrum over the entire high-energy band. This is crucial for the detection of counterparts of gravitational waves (GWs) and neutrino candidate events.

The aim of this project is, therefore, to develop a collaborative platform, the **AFIS platform**, to enable collaboration between the high-energy (HE) satellites with INAF participation, for prompt electromagnetic waves, GW and neutrino counterpart searches. This activity is achieved by exchanging alerts from electromagnetic, LIGO/Virgo collaborations and neutrino facilities, to obtain information of the scientific results generated by the AFIS facilities. This platform will also include GRB alerts.

The **AFIS** platform will allow sharing sub-threshold events between AFIS facilities in the multi-messenger/multi-wavelength context. The next O4 Ligo-Virgo observation period will start in May 2023 and last for at least one year, possibly up to the end of 2024. A temporal correlation of sub-threshold events of AFIS observatories is hence mandatory. A more comprehensive joint use of the multiwavelength information is fundamental to 1) unveil features of high-energy processes, 2) increase the rate of detectable sources by accessing lower amplitude events, 3) improve the estimates of the localization and other important characteristics of the source. This will enable more successful follow-up campaigns of the proposers of the project, and increase the population of sources with identified counterparts.

2. AFIS Platform

The AFIS platform is a software system that aims to collect scientific results from the facilities and share these results inside the AFIS collaboration. AFIS receives science alerts from external sources such as the GCN network.

In addition, the facilities part of the AFIS project can send their sub-threshold event to the AFIS platform that searches for a time correlation in a time window. The platform will send a notification to the AFIS Team in case a correlation is found.

The AFIS project is described in three documents:

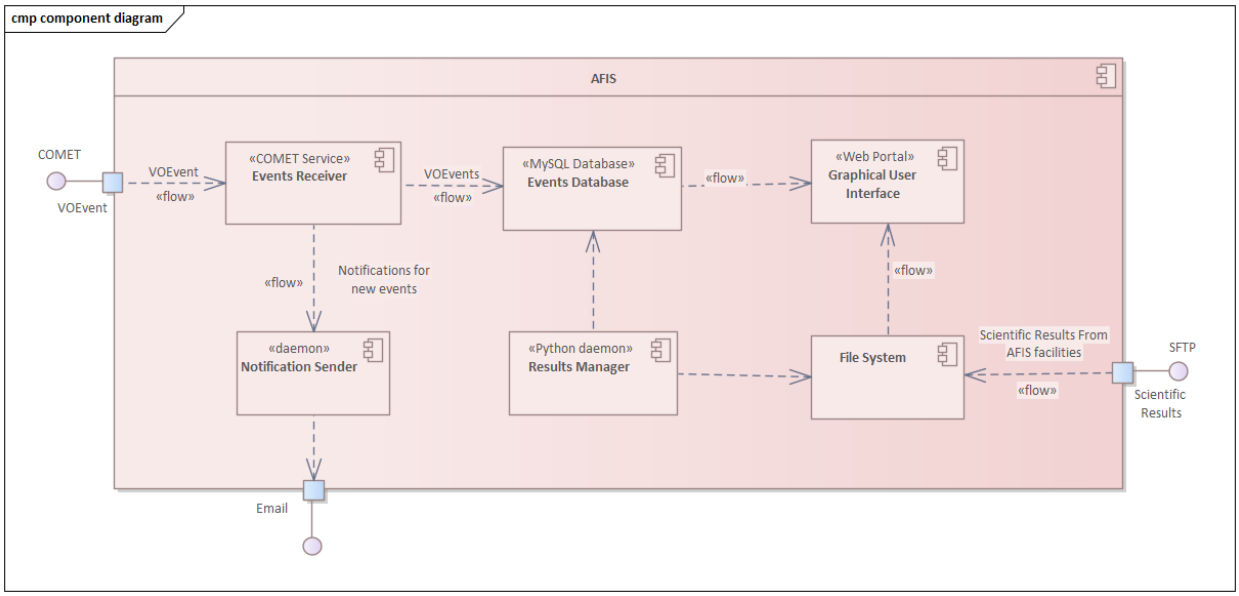
1) AFIS Platform Use Cases, **ANNEX 1**
2) AFIS Platform Software Detailed Design, **ANNEX 2**
3) AFIS User Manual, **ANNEX 3**

The AFIS platform was presented at the Astronomical Data Analysis Software and System XXXII conference (31 October – 4 November 2022). The proceeding is under publication and for now available on arXiv (https://arxiv.org/abs/2302.07876).

The AFIS platform is composed of the following components also shown in the following figure:

1. Events Receiver: this software component is implemented using the COMET framework and aims to receive standard events (Science Alerts) from the GCN network and sub-threshold events from the real-time analysis (RTA) pipelines of the AFIS facilities. These events are then stored in the Events Database.
2. Notification Sender: this software component sends emails to the AFIS team when a new event is received by the system. It can be configured to notify different types of events.
3. Events Database: this database stores the standard events and sub-threshold.

4. File System: the file system of the host machine where the AFIS platform is deployed stores the scientific results sent by the AFIS RTA pipelines (e.g., images and plots).
5. Results Manager: this software component organizes the scientific results received by the RTA pipelines of the AFIS facilities inside the file system.
6. Graphical User Interface: the AFIS team can visualize the scientific results and the list of events using this web portal.



Component diagram of the AFIS platform.

The code developed for this project is managed using Git and is stored in these GitHub repositories:

1. https://github.com/ASTRO-EDU/AFIS-containers
2. https://github.com/ASTRO-EDU/AFIS-GUI
3. https://github.com/ASTRO-EDU/AFIS-pipeline

For now, these repositories are not public due to security reasons. To request access to them, it is possible to send an email to nicolo.parmiggiani@inaf.it with the name of the GitHub user.

To implement this platform, we used the following services and frameworks:

1. **COMET** is an implementation of the VOEvent Transport Protocol. It provides automated mechanisms to develop a platform that can send and receive VOEvents. The VOEvent is a standard data format to share transient celestial events.

2. **Python** is a programming language largely used by the scientific community.

3. **MySQL** is an open-source and free relational database management system.

3. AFIS Facilities.

AGILE is an ASI space mission for high-energy astrophysics in an equatorial orbit [RD2]. The AGILE payload consists of (1) the Gamma-Ray Imager Detector (GRID, 30 MeV - 30 GeV), (2) a Mini-Calorimeter (MCAL, 350 keV - 100 MeV), and (3) a hard X-ray imager (Super-AGILE, 18 - 60 keV). The GRID has an excellent angular resolution, and a very large field of view (FoV), 2.5 sr. Super-AGILE is co-

axial with the GRID with a FoV of 1 sr. AGILE is currently operating in spinning mode scanning about 80% of the entire sky with about 200 revolutions per day. Data are routinely acquired, archived [RD3] and processed by a real-time analysis system [RD4,RD5].

Fermi is a NASA space mission whose instrument consists of (1) the Gamma-ray Burst Monitor (GBM) sensitive in the 8 keV–40 MeV band [RD7], and (2) the Large Area Telescope (LAT) operating in the 20 MeV – 300 GeV band [RD8]. LAT has a very large FoV of 2.4 sr and monitors the entire sky every 3 hours. Fermi mission data are continuously downloaded: LAT data are immediately publicly available, and GBM data are promptly analyzed and alerts are automatically generated. LAT can position gamma-ray transients within 1-2 degrees and be extremely useful for searching GW event counterparts.

INTEGRAL [RD9] is an ESA space observatory designed for imaging and spectroscopy of cosmic sources in the 10 keV -10 MeV band. The main instruments are: (1) the imager IBIS [RD10] with sub-arcmin angular resolution over a 30x30 square degree FoV, and (2) the spectrometer SPI. Both instruments have active anticoincidence shielding (VETO and ACS, respectively) that can independently detect transient gamma-ray events over the full sky. INTEGRAL orbits around the Earth in 2.6 days, resulting in a continuous scientific duty cycle of 2.25 days with no Earth occultation.

Swift (the Neil Gehrels NASA Observatory) [RD11] is focused on GRBs and X-ray transient events. It is made of three instruments: (1) the Burst Alert Telescope (BAT) [RD12] a 15–350 keV coded-mask detector with a FoV near 2 sr; (2) the X-ray Telescope (XRT), a 0.3–10 keV focusing instrument with a FoV of 0.13 deg2; (3) the UV/optical telescope UVOT sensitive in the ultraviolet band. BAT has currently detected more than 1300 GRBs, including ~120 short-GRBs, localising them to within ~3 arcmins at trigger time. When a new GRB is detected or is commanded from a ground alert, Swift can repoint automatically within 60-120 sec and starts data acquisition with XRT and UVOT.

ANNEX Documents

AFIS platform
Use Cases

Prepared by:	Name:	A. Bulgarelli, N. Parmiggiani	Date:	Jul 31, 2022

Main Authors: A. Bulgarelli, N. Parmiggiani
Contributor Authors: A. Addis, J. Rodi, A. Bazzano.

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DOCUMENT HISTORY		
Version	**Date**	**Modification**
1.0	Sept 15, 2021	First release
1.1	Jul 31, 2022	Updates on use cases

1. Introduction

The rapid detection of high-energy transients by multi high-energy satellites represent a key step to increase the significance of the high-energy candidate events, to improve their localization, and to cover the source spectrum over the entire high-energy band. This is crucial for the detection of counterparts of gravitational waves (GWs) and neutrino candidate events.

The aim of this project is, therefore, to develop a collaborative platform, the **AFIS platform**, to enable a joint collaboration between the high-energy (HE) satellites with INAF participation, for prompt e.m. GW and neutrino counterpart searches. This activity is achieved by exchanging alerts from e.m., LIGO/Virgo collaborations and neutrino facilities, to obtain information of the scientific results generated by the AFIS facilities. This platform will also include GRB alerts.

The same collaborative platform allows sharing sub-threshold events between AFIS facilities in the multi-messenger/multi-wavelength context. The next O4 Ligo-Virgo observation period will start in early 2023 and last for at least one year. A temporal correlation of sub-threshold events of AFIS observatories is mandatory. A more comprehensive joint use of the multiwavelength information is fundamental to 1) unveil features of high-energy processes, 2) increase the rate of detectable sources by accessing lower amplitude events, 3) improve the estimates of the localization and other important characteristics of the source. This will enable more successful follow-up campaigns of the proposers of the project, and increase the population of sources with identified counterparts.

The **AFIS platform** will provide a **dashboard** through a web portal that will show the list of science alerts received from the GCN network [RD6], a summary of the results of the AFIS facilities and a list of sub-threshold events with possible time correlation.

1.1. Purpose

This document described the use cases of a platform (a.k.a the AFIS system, or the system) to collect the results of prompt analyses executed on the data acquired by the AGILE, Fermi, INTEGRAL and SWIFT (AFIS) missions, in reaction to

1. standard events
2. sub-threshold events.

The intended reader of this document are the scientists that shall use the system and the software engineers/developers.
All events from AFIS facilities are received through GCN network. For the time being we will make use of AGILE and INTEGRAL sub-threshold events.
The use cases are divided into three main groups following the functional decomposition of the system:

1. Collection of science results from AFIS facilities for standard events
2. Notification and time correlation on sub-threshold events
3. Manual collection of sub-threshld events from AGILE and INTEGRAL facilities.

4. Web Graphical User Interface (GUI)

1.2. Scope

The AFIS system is part of the WP 12.2 of the AHEAD2 project.

1.3. Content

The document is structured as follows:

- Section 2 lists the applicable and reference documents;
- Section 3 lists the actors that interact with the AFIS platform;
- Section 4 shows an overview of the software system;
- Section 5 presents the use cases.

1.4. Definitions and Conventions

Facility: an observatory or experiment that generates science alerts or shares results and information on the target of a science alert.

Standard event: The standard events are science alerts on transient events detected by astrophysical facilities above the predefined significance threshold that allow the external communication, or from external observatories in the Multi-Messenger (MM) / Multi-Wavelength (MW) context and shared through the communication networks.

Science Alert: A science alert is a communication via GCNs or Atels from/to the astrophysical community that a transient phenomenon occurs in the sky.

Subthreshold event: a transient events detected by astrophysical facilities below a predefined significance threshold that does not allow an external communication

Science Target: see *Target*

Target: Celestial object or ROI that is described in a science alert or in a subthreshold event and that can be observed by astronomical facilities.

Trigger facility: the first facility that shares a science alert on a specific target.

Trigger science alert: the first science alert shared by the trigger facility.

1.5. Abbreviations and acronyms

DPM: Data Processing Manager
GCN: General Coordinates Network
GUI: Graphical User Interface

2. Applicable and reference documents

2.1. Applicable documents

[AD1] Luigi Piro et al. *"Integrated Activities for the High Energy Astrophysics Domain."* Call: H2020-INFRAIA-2018-2020. Topic: INFRAIA-01-2018-2019, Proposal number: 871158 Proposal acronym: AHEAD2020.

2.2. Reference documents

[RD1] Ferrigno C. et al.,,Multi-messenger Astronomy with INTEGRAL, 2021, new AR, 92, id.101595

[RD2] Tavani, M., "The AGILE Mission", Astronomy and Astrophysics, vol. 502, no. 3, pp. 995–1013, 2009. doi:10.1051/0004-6361/200810527.

[RD3] Pittori, C. and the AGILE-SSDC Team, "The AGILE data center and its legacy", Rendiconti Lincei. Scienze Fisiche e Naturali, vol. 30, pp. 217–223, 2019. doi:10.1007/s10686-019-09644-w.

[RD4] Bulgarelli, A., "The AGILE Gamma-Ray observatory: software and pipelines", Experimental Astronomy, vol. 48, no. 2–3, pp. 199–231, 2019. doi:10.1007/s10686-019-09644-w.

[RD5] Parmiggiani, N., "The AGILE real-time analysis pipelines in the multi-messenger era", in 37th International Cosmic Ray Conference. 12-23 July 2021. Berlin, 2022. arXiv.

[RD6] Barthelmy, S. D., "GRB Coordinates Network (GCN): A status report", in Gamma-ray Bursts, 5th Huntsville Symposium, 2000, vol. 526, pp. 731–735. doi:10.1063/1.1361631.

[RD7] Meegan, C., "The Fermi Gamma-ray Burst Monitor", The Astrophysical Journal, vol. 702, no. 1, pp. 791–804, 2009. doi:10.1088/0004-637X/702/1/791.

[RD8] Ackermann, M., "The Fermi Large Area Telescope on Orbit: Event Classification, Instrument Response Functions, and Calibration", The Astrophysical Journal Supplement Series, vol. 203, no. 1, 2012. doi:10.1088/0067-0049/203/1/4.

[RD9] Winkler, C., "The INTEGRAL mission", Astronomy and Astrophysics, vol. 411, pp. L1–L6, 2003. doi:10.1051/0004-6361:20031288.

[RD10] Ubertini, P., "IBIS: The Imager on-board INTEGRAL", Astronomy and Astrophysics, vol. 411, pp. L131–L139, 2003. doi:10.1051/0004-6361:20031224.

[RD11] Gehrels, N., "The Swift Gamma-Ray Burst Mission", The Astrophysical Journal, vol. 611, no. 2, pp. 1005–1020, 2004. doi:10.1086/422091.

[RD12] Barthelmy, S. D., "The Burst Alert Telescope (BAT) on the SWIFT Midex Mission", Space Science Reviews, vol. 120, no. 3–4, pp. 143–164, 2005. doi:10.1007/s11214-005-5096-3.

3. Actors

This sectionprovides the definitions of all actors involved in the use cases, or put a reference to external descriptions.

3.1. Human actors

Science User (a.k.a. scientist): a member of one of the AFIS facilities that will interact with the **AFIS platform** to check the results provided by facilities in reaction to external and internal science alerts, both standard or sub-threshold.

Data Processing Manager (**DPM**): responsible for the AFIS system operations.

3.2. Systems

AFIS Platform: the software system

3.3. AFIS facilities

AGILE is an ASI space mission for high-energy astrophysics in an equatorial orbit [RD2]. The AGILE payload consists of (1) the Gamma-Ray Imager Detector (GRID, 30 MeV - 30 GeV), (2) a Mini-Calorimeter (MCAL, 350 keV - 100 MeV), and (3) a hard X-ray imager (Super-AGILE, 18 - 60 keV). The GRID has an excellent angular resolution, and a very large field of view (FoV), 2.5 sr. Super-AGILE is co-axial with the GRID with a FoV of 1 sr. AGILE is currently operating in spinning mode scanning about 80% of the entire sky with about 200 revolutions per day. Data are routinely acquired, archived [RD3] and processed by a real-time analysis system [RD4,RD5].

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3.4. Communication networks

The **GCN service** [RD6] is an automated service (without human intervention) that distributes the sky position coordinates of transient phenomena (e.g GRBs, GW and neutrinos) to the community in real-time. The GCN network can manage two types of communications: (i) **circulars** in a human-readable format and (ii) **notices** to be interpreted by automated software. The observatories can subscribe to the GCN notification channel, selecting the list of facilities from which they want to receive science alerts.

The **Astronomer's Telegram (ATel) service** is an internet-based service where researchers can publish their short communication about transient phenomena or follow up the results of other observatories. This service is not developed as the GCN network for automated software.

4. Overview of the system

The **AFIS platform** provides a collaborative environment allowing a seamless flow of information of science alerts and sub-threshold events, enabling also the time ***correlation of sub-thresholds*** event to respond effectively to external GW alerts to maximize the scientific return. The ability to ***issue notifications with coincidence sub-threshold*** events rapidly is a key feature of the proposed system. This platform enables a stream of information (automatic and with human intervention) for a cross-check between GW events, neutrino and GRB events, to promptly identify astrophysical events in close temporal and spatial coincidence with science alerts or to optimize follow-ups.
The platform will menage

1. Standard events
2. Sub-threshold events (STE).

The first requirement is a coordinated and automated flow of events from the following instruments:

Science alerts:

1. AGILE MCAL instruments
2. Fermi GBM e LAT,
3. Swift, BAT ratemeters e imagin
4. INTEGRAL ACS/SPI, Veto and PiCsIt/IBIS
5. LVC
6. ICECUBE

Sub-threshold events:

1. AGILE MCAL
2. INTEGRAL ACS/SPI

The **events** are used to promptly identify astrophysical EM events in close temporal coincidence with a standard event or STE. The fast data stream allows the proposing team to identify:

- High significance prompt and delayed EM emission from the AFIS facilities
- sub-threshold possible interesting events in the AGILE and INTEGRAL data stream and possibly correlate them with science alerts.

The platform must be able to send an email in coincidence with a GW or neutrino event, or if multiple coincidences of events are found inside the stream of data of the facilities.

The platform is connected with the networks of science alerts (public and inside the collaborations).

5. Use Cases

1. AFIS-UC-100: Receive an external science alert
2. AFIS-UC-200: An AFIS facility uploads scientific results
3. AFIS-UC-300: The AFIS Platform receives a sub-threshold event
4. AFIS-UC-400: The AFIS Platform shows the results of analyses through a web platform

5.1. AFIS-UC-100: Receive an external science alert

Summary and Scope: The AFIS platform receives an external science alert. The AFIS facilities share information on results.

Authors: A. Bulgarelli

Version: 1.0

Trigger:

Frequency: For each external science alert

Phase: production

Assumptions:

PRE-CONDITION CONSTRAINTS
The **AFIS platform** is connected with the **GCN network**.
SCENARIOS
Basic Path. 1. The **AFIS Platform** receives an external science alert from the **GCN network** from a “trigger facility”. The **AFIS Platform** creates a new web page for the event (the target of the science alert). 2. The **Science User** is notified with an email if the science alert is related to a GW or a neutrino event. *Assumption: wake-up systems and shifts are managed internally by the AFIS teams.* 3. The **AFIS Platform** receives public or confidential scientific results from GCN network as soon as they are available. The following AFIS facilities are foreseen: 3.1. AGILE MCAL instrument, 3.2. Fermi GBM e LAT, 3.3. Swift, BAT, 3.4. Integral ACS/SPI, Veto and PiCsIt/IBIS. 3.5 ICECUBE 3.6 LVC

4. The **Science User** is notified with an email.

5. The **AFIS Platform** receives science alert updates from GCN

> Alternate: *5a*, *The **AFIS Platform** receives additional science alerts of the same target from different facilities* (See details below). Rejoins Main Scenario at step 6.
> Alternate: *5b*, *The **AFIS Platform** receives updates of the same event from the same facility* (See details below). Rejoins Main Scenario at step 6.

6. The **AFIS Platform** searches for a time correlation in a time window between events. The platform sends a notification to the **Science User** if a correlation is found.

7. The **Science User** checks the science alert through a web platform (AFIS-UC-400)

Alternate. *The **AFIS Platform** receives additional science alerts of the same event from different facilities*

1. The **AFIS Platform** correlates from a temporal point of view new science alerts of the same target
2. The **AFIS Platform** displays in a unified view all information on the same target.

Alternate. *The **AFIS Platform** receives updates of the same event from the same facility*

> *Note: there are some science alerts that already include the possibility to track the updates (e.g. LV).*

1. The **AFIS Platform** displays updated information on the same target with all the history of the alerts received from the facility.

POST CONDITION CONSTRAINT

MINIMAL GUARANTEE

The trigger science alerts are received.

SUCCESS GUARANTEE

Science alerts are received.
Correlated science alerts on the same targets and updates are shown by the **AFIS Platform**

OPEN POINTS

5.2. AFIS-UC-200: An AFIS facility uploads scientific results

Summary and Scope: An AFIS facility uploads scientific results related to a Science Target to the AFIS platform. This upload of data can be performed automatically by the pipelines or manually by the researchers of the facilities.

Authors: N. Parmiggiani

Version: 1.0

Trigger: The AFIS facilities produces results related to a **Science Target**

Frequency: Several times for each external **Science Target**

Phase:

Assumptions:

PRE-CONDITION CONSTRAINTS
The **AFIS platform** and its services (e.g. MySQL) are up and running
SCENARIOS
Basic Path: automated upload. 1. The automated pipelines of the AFIS facilities send the scientific results related to a **Science Target** to the **AFIS platform** 2. The **AFIS platform** manages the information received and collects all information related to the same Science Target sent by different facilities. **Basic Path: manual upload.** 1. The **Science User** performs the login into the AFIS web portal using the credentials assigned to him/her. 2. The **Science User** select the web page related to the **Science Target** and manually upload the results obtained by the facility (e.g. sky maps and light curves) 3. The **AFIS platform** manages the information received and collects all information related to the same Science Target sent by different facilities.
POST CONDITION CONSTRAINT
MINIMAL GUARANTEE
SUCCESS GUARANTEE
Results from AFIS facilities are uploaded.
OPEN POINTS

5.3. AFIS-UC-300: The AFIS Platform receives a sub-threshold event

Summary and Scope: The AFIS platform receives a sub-threshold event from an AFIS facility. The AFIS facilities share information and results.

Authors: A. Bulgarelli

Version: 1.0

Trigger:

Frequency: For each sub-threshold event

Phase: production

Assumptions:

PRE-CONDITION CONSTRAINTS
SCENARIOS
Basic Path. 1. The **AFIS Platform** receives a sub-threshold event from an **AFIS facility**. The **AFIS Platform** creates a new web page for the target of the sub-threshold event. 2. The **Science User** is notified with an email. 3. The **AFIS Platform** could receive public or confidential scientific results from AFIS facilities as soon as they are available. 4. The **Science User** checks the results of analyses through a web platform (AFIS-UC-400) 5. Manual analysis and decisions are foreseen by **AFIS collaboration**.
POST CONDITION CONSTRAINT
MINIMAL GUARANTEE
The sub-threshold events are received.
SUCCESS GUARANTEE
The sub-threshold events are received. Results from AFIS facilities are uploaded
OPEN POINTS

5.4. AFIS-UC-400: AFIS shows the results of analyses through a web platform

Summary and Scope: The AFIS platform provides a web portal where the users can visualize the status of facilities and the results of analyses performed.

Authors: N. Parmiggiani

Version: 1.0

Trigger: When the user what to visualize the AFIS platform information

Frequency: Several times per day

Phase:

Assumptions:

PRE-CONDITION CONSTRAINTS

The **AFIS platform** and its services (e.g. web server, database) are up and running

SCENARIOS

Basic Path.

1. The **AFIS Platform** allows the **Science User** and the **DPM** to access the password protected web portal remotely.
2. The **Science User** and the **DPM** login into the AFIS web portal.

   Exception: *1a*, *The user can not login into the system.*

3. The **Science User** and the **DPM** visualize the home page of the web site with the list of science alerts received by the GCN network or the web page with the list of STEs.
4. The **Science User** and the **DPM** can open the detail page related to a science alert or an STE and visualize the information collected by the AFIS facilities:
   a. scientific results obtained from each facility and sent to the AFIS platform
   b. science alert information
   c. a list of science alerts and sub-threshold events correlated with the target
   d. the history of events sent by the trigger facility related to the target

Exception. *The user can not login into the system.*

1. The **AFIS Platform** shows an error message.

POST CONDITION CONSTRAINT

MINIMAL GUARANTEE

SUCCESS GUARANTEE
OPEN POINTS

AFIS Platform Software Detailed Design

Prepared by:	Name:	N. Parmiggiani, A. Addis, J. Rodi	Date:	Jul 31, 2022

Main Authors: N. Parmiggiani, A. Addis, J. Rodi
Contributor Authors: A. Bulgarelli, A. Bazzano.

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Version	***Date***	***Modification***
1.0	Nov 5, 2021	First release of the draft
1.1	Jul 31, 2022	Updates based on UCD 1.1

1. Introduction

AFIS is a collaborative platform that receives external science alerts from e.m., GW and neutrino observatories.
The same collaborative platform allows sharing sub-threshold events, with a joint cross check of time coincidences of participating observatories with external science alerts. A more comprehensive joint use of the multiwavelength information is fundamental to 1) unveil features of high-energy processes, 2) increase the rate of detectable sources by accessing lower amplitude events, 3) improve the estimates of the localization and other important characteristics of the source. This will enable more successful follow-up campaigns of the proposers of the project, and increase the population of sources with identified counterparts.

The **AFIS platform** provides a **dashboard** through a web portal that shows a summary of the science alerts, a summary of the results of some AFIS facilities and a list of s events with possible time correlation.

1.1. Purpose

This document describes the software architecture and design of the **AFIS** platform.

The software architecture is defined by looking at the system from different viewpoints and is then illustrated through different views (see Fig. 1):

1) **Logical/Functional View**: a functional decomposition of the system with the description of the global information flow (based on the analysis of Use Cases and Data Models). UML diagrams are used to represent the logical view;
2) **Process View**: deals with the dynamic aspect of the system.
3) **Implementation/Development View:** represents the detailed design of the implemented system.
4) **Physical/Deployment View:** The physical view depicts the system from a system engineer's point of view. It is concerned with the topology of software components on the physical layer as well as the physical connections between these components. This view is also known as the deployment view. Physical view is more concerned with the physical layer of the system, deployment view with the allocation of computing resources on physical nodes;
5) **Use Case View:** A use case is a list of actions or event steps typically defining the interactions between an actor and a system to achieve a goal. The actor can be a human or other system. In this context UCs specify directly functional requirements, and each UC constitutes a functional specification.

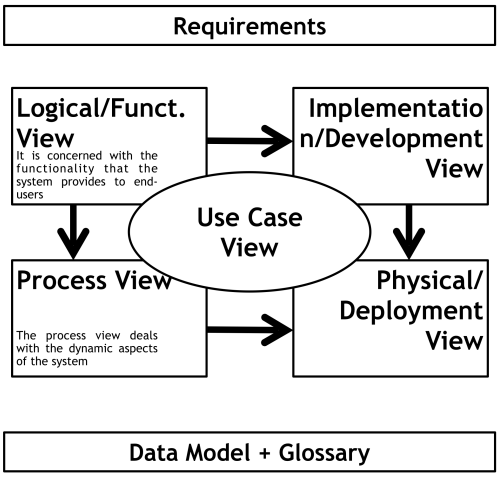

Figure 1: Illustration of the 4+1 Architectural View Model with Requirements and Data Model and Glossary as a foundation.

1.2. Scope

The AFIS system is part of the WP 12.2 of the AHEAD2 project.

1.3. Content

The document is structured as follows:

- Section 2 lists the applicable and reference documents.
- Section 3 describes the system context, the design decision, the software dependencies, and the interfaces.
- Section 4 describes the design of the software architecture and lists all the software components.
- Section 5 shows the data models for the input and the output. In addition, this section describes the configuration files to operate the software system.
- Section 6 shows the activity diagrams of the main workflow during the management of science alerts and sub-threshold events.
- Section 7 describes the deployment of the system.

1.4. Abbreviations and acronyms

AFIS	AGILE, Fermi, Integral, Swift
GCN	Gamma-ray Coordinates Network
RTA	Real-Time Analysis
SFTP	SSH File Transfer Protocol
VM	Virtual Machine
XML	Extensible Markup Language

2. Applicable and reference documents

2.1. Applicable documents

[AD1] AFIS Platform Use Cases. Issue 1.0, 15-Sept-2021.

2.2. Reference documents

[RD1] Luigi Piro et al. *"Integrated Activities for the High Energy Astrophysics Domain."* Call: H2020-INFRAIA-2018-2020. Topic: INFRAIA-01-2018-2019, Proposal number: 871158 Proposal acronym: AHEAD2020.

3. System overview

3.1. Overall Description

The **AFIS platform** is a software system that aims to collect scientific results from the facilities and share these results inside the AFIS collaboration. AFIS receives science alerts from external sources such as the GCN network.

In addition, the facilities part of the AFIS project can send their sub-threshold event to the AFIS platform that searches for a time correlation in a time window. The platform sends a notification to the AFIS Team if a correlation is found.

3.2. System Context

The system context where the AFIS platform operates is shown in Figure 2. The platform is a subscriber of the GCN network that sends science alerts in the VOEvent data format. AFIS can manage these events using the COMET framework (https://comet.transientskp.org/). COMET can also receive direct VOEvents from the real-time analysis (RTA) pipelines of the space missions part of the project (AGILE and INTEGRAL). The RTA pipelines send scientific results (sky maps, light curves, etc.) through an SFTP connection to the AFIS system. Finally, when the platform receives new science alerts or finds the time correlation between sub-threshold events, it sends a notification to the AFIS Team.

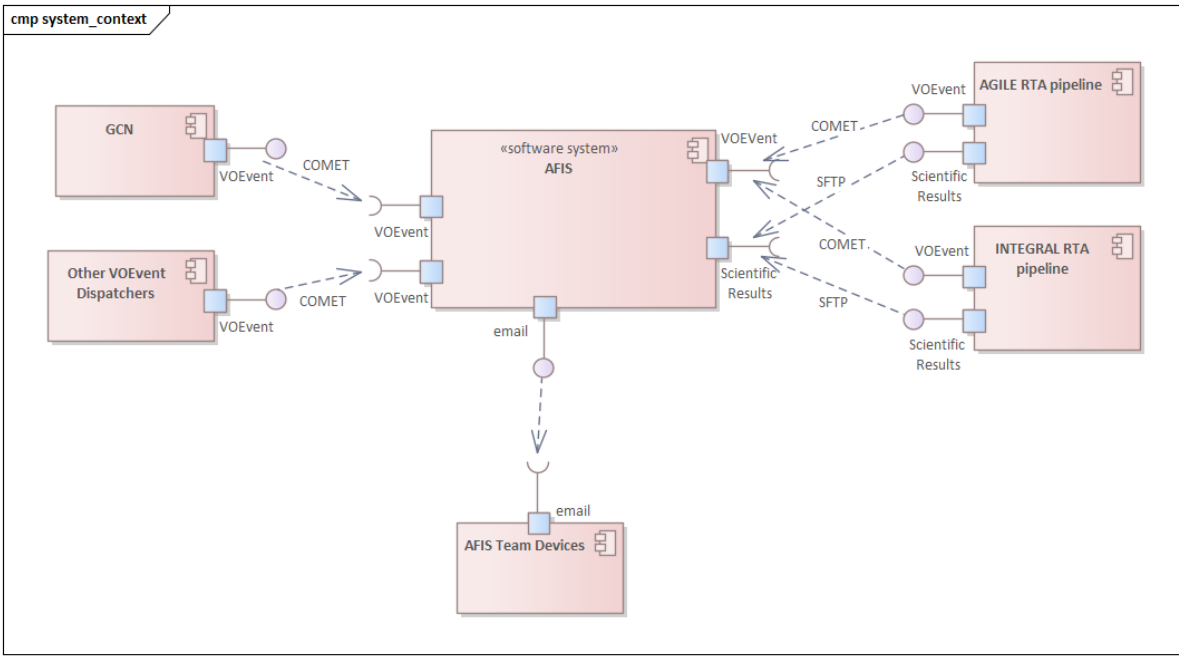

Figure 2: System context of the AFIS platform.

3.3. Design decisions

3.3.1. COMET

ID	AFIS-SDD-01
Description	
COMET is an implementation of the VOEvent Transport Protocol. It provides automated mechanisms to develop a platform that can send and receive VOEvents. The VOEvent is a standard data format to share transient celestial events.	
Pros & Opportunities	
• Easy-to-use Python framework to manage Science Alerts. • Real-time science alerts handling. • It can subscribe to other services such as the GCN network to receive science alerts or publish events to the community.	

• It can receive direct events from the facilities' pipelines to the COMET service that we implemented for AFIS.
Cons & Risks
• The COMET framework is maintained only by one person. • The commit history shows a minimal effort in the last period
Assumptions and Quantification
• The COMET framework will be maintained in the next years
Trade-offs
• The COMET framework can manage events received by the GCN and by other custom sources in the VOEvent format. These features satisfy the AFIS requirement on the management of events. We think that the risks are lower than pros.

3.3.2. Python

ID	**AFIS-SDD-02**
Description	
Python is a programming language largely used by the scientific community.	
Pros & Opportunities	
• Fast learning curve. • Reduced development time. • Several ready-to-use external libraries.	
Cons & Risks	
• Lower performances than compiled languages (e.g., C++).	
Assumptions and Quantification	

• Python is well documented and will be supported in the next years • Python is largely used by the community and it is easy to find expert developers
Trade-offs
• The fast development time and learning curve are more important in the AFIS software than the computing performances.

3.3.3. MySQL

ID	**AFIS-SDD-02**
Description	
MySQL is an open-source and free relational database management system.	
Pros & Opportunities	
• MySQL is largely used in the scientific community. • It is free and open-source. • MySQL has a huge support community. • It is ACID compliant (Atomicity, Consistency, Isolation and Durability) with the InnoDB engine.	
Cons & Risks	
• Not suitable for Big Data Management.	
Assumptions and Quantification	
• MySQL will be maintained in the next years.	
Trade-offs	
• The fast development time and learning curve are more important in the AFIS software than the computing performances.	

3.4. Software Dependencies

The software is implemented using external libraries and software:

Dependency	Version
Python	3.8.13
Astropy	5.0.1
Comet	3.1.0
ligo.skymap	1.0.0
ligo.gracedb	2.7.7
ligo.segments	1.4.0
lxml	4.8.0
mysql-connector-python	8.0.29
python-ligo-lw	1.8.0
Twisted	22.2.0
voevent-parse	1.0.3

3.5. External Interfaces

3.5.1. AFIS and the GCN network

3.5.1.1. Functions

The AFIS platform receives from the GCN network information about the external science alerts.

3.5.1.2. Required Interfaces

The AFIS platform receives the science alert using the COMET framework. The information is formatted with the VOEvent format.

3.5.2. AFIS and the AGILE pipeline

3.5.2.1. Functions

The AFIS platform receives the scientific results from the AGILE RTA pipelines related to a science alert.

3.5.2.2. Required Interfaces

The scientific results are sent using the SFTP transfer protocol.

3.5.3. AFIS and the INTEGRAL pipeline

3.5.3.1. Functions

The AFIS platform receives the scientific results from the INTEGRAL RTA pipelines related to a science alert.

3.5.3.2. Required Interfaces

The scientific results are sent using the SFTP transfer protocol.

3.5.4. AFIS and the AGILE RTA pipeline for STE events

3.5.4.1. Functions

The AFIS platform can receive sub-threshold events from the AGILE RTA pipeline.

3.5.4.2. Required Interfaces

The sub-threshold events are sent using the COMET framework. The information is formatted with the VOEvent format (Section 5.1).

3.5.5. AFIS and the INTEGRAL RTA pipeline for STE events

3.5.5.1. Functions

The AFIS platform can receive sub-threshold events from the INTEGRAL RTA pipeline.

3.5.5.2. Required Interfaces

The sub-threshold events are sent using the COMET framework. The information is formatted with the VOEvent format (Section 5.1).

3.5.6. AFIS and the AFIS Team

3.5.6.1. Functions

The AFIS platform sends a notification to the AFIS team when a new event is received

3.5.6.2. Required Interfaces

The notifications are sent as email.

4. System design

4.1. Decomposition description

The **AFIS** implements the following components shown in Figure 3:

- **Events Receiver**: this software component is implemented using the COMET framework and aims to receive standard events (Science Alerts) from the GCN network and sub-threshold events from the real-time analysis (RTA) pipelines of the AFIS facilities. These events are then stored in the **Events Database**.
- **Notification Sender**: this software component sends emails to the AFIS team when a new event is received by the system. It can be configured to notify different types of events.
- **Events Database:** this database stores the standard events and sub-threshold.
- **File System:** the file system of the host machine where the AFIS platform is deployed stores the scientific results sent by the AFIS RTA pipelines (e.g., images and plots).
- **Results Manager:** this software component organizes the scientific results received by the RTA pipelines of the AFIS facilities inside the file system.
- **Graphical User Interface:** the AFIS team can visualize the scientific results and the list of events using this web portal.

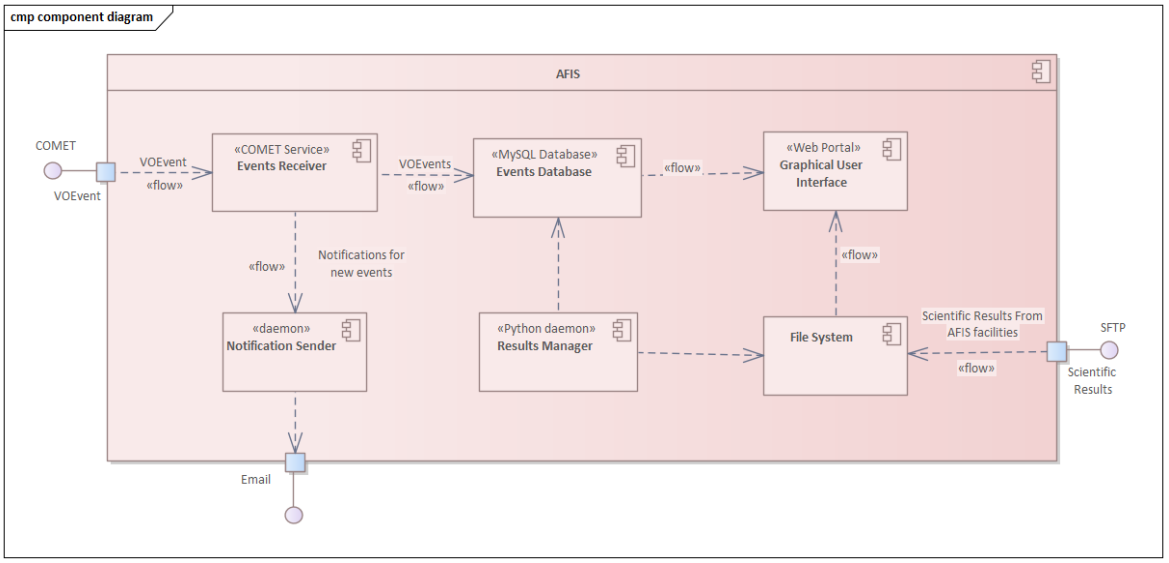

Figure 3: Component diagram of the AFIS platform.

5. Data model

5.1. Input data

5.1.1. VOEvents for science alerts

The VOEvents that the AFIS platform receives from the GCN are defined in the test suite of the code. In addition, they are shown in the GCN documentation related to each facility.

5.1.2. VOEvents for STE

INTEGRAL STE VOEvent example

```
<?xml version='1.0' encoding='UTF-8'?>
<voe:VOEvent       xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:voe="http://www.ivoa.net/xml/VOEvent/v2.0"
xsi:schemaLocation="http://www.ivoa.net/xml/VOEvent/v2.0
http://www.ivoa.net/xml/VOEvent/VOEvent-v2.0.xsd"          version="2.0"
role="test" ivorn="INTEGRAL/dummy/demo#1">
 <Who>
    <Description>VOEvent created with voevent-parse, version 1.0.3. See
https://github.com/timstaley/voevent-parse for details.</Description>
   <AuthorIVORN>ivo://INTEGRAL/dummy_demo</AuthorIVORN>
   <Date>2022-05-20T11:10:32</Date>
   <Author>
     <contactName>James Rodi</contactName>
     <title>Hotwired VOEvent Hands-on</title>
   </Author>
 </Who>
 <What>
   <Param name="TrigID" value="7654321" ucd="meta.id" />
   <Param ucd="phot.mag" value="18.77" name="mag" dataType="float"/>
   <Group name="historic">
               <Param   ucd="phot.mag"   value="19.62"   name="hist_mag"
dataType="float"/>
             <Param   ucd="phot.mag"   value="0.07"   name="hist_scatter"
dataType="float"/>
   </Group>
   <Param ucd="phot.mag" value="18.77" name="mag" dataType="float"/>
   <Group name="historic">
               <Param   ucd="phot.mag"   value="19.62"   name="hist_mag"
dataType="float"/>
```

```
            <Param   ucd="phot.mag"   value="0.07"   name="hist_scatter"
dataType="float"/>
   </Group>
 </What>
 <WhereWhen>
   <ObsDataLocation>
     <ObservatoryLocation id="INTEGRAL"/>
     <ObservationLocation>
       <AstroCoordSystem id="UTC-FK5-GEO"/>
       <AstroCoords coord_system_id="UTC-FK5-GEO">
         <Time unit="s">
           <TimeInstant>
             <ISOTime>2022-05-30T11:10:32</ISOTime>
           </TimeInstant>
         </Time>
         <Position2D unit="deg">
           <Name1>RA</Name1>
           <Name2>Dec</Name2>
           <Value2>
             <C1>314.6578836056712</C1>
             <C2>12.45</C2>
           </Value2>
           <Error2Radius>0</Error2Radius>
         </Position2D>
       </AstroCoords>
     </ObservationLocation>
   </ObsDataLocation>
 </WhereWhen>
    <Description>This    is    not    an    official    INTEGRAL    data
product.</Description>
</voe:VOEvent>
```

AGILE STE VOEvent example

```
<?xml version='1.0' encoding='UTF-8'?>
<voe:VOEvent      xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:voe="http://www.ivoa.net/xml/VOEvent/v2.0"
xsi:schemaLocation="http://www.ivoa.net/xml/VOEvent/v2.0
http://www.ivoa.net/xml/VOEvent/VOEvent-v2.0.xsd"          version="2.0"
role="test" ivorn="ivo://AGILE.txt#1">
 <Who>
    <Description>VOEvent created with voevent-parse, version 1.0.3. See
https://github.com/timstaley/voevent-parse for details.</Description>
   <AuthorIVORN>ivo://AGILE_MCAL_TRIGGER/</AuthorIVORN>
   <Date>2022-05-30T11:10:32</Date>
   <Author>
     <contactName>Andrea Bulgarelli</contactName>
     <title>AGILE-MCAL TRIGGER ALERT NOTICE</title>
   </Author>
 </Who>
```

```
 <What>
 <Param name="TrigID" value="585679841" ucd="meta.id" />
 <Param name="grb.total.counts" value="29" ucd="" unit="counts"/>
 <Param name="grb.signif" value="3.40" ucd="" unit="sigma" />
 <Param name="background" value="15" ucd="" unit="counts/0.032 sec" />
 <Param name="data.time.scale" value="0.032" ucd="" unit="sec" />
 <Param name="integ.time" value="0.029" ucd="" unit="sec" />
 <Param name="energy.min" value="400" ucd="" unit="keV" />
 <Param name="energy.max" value="100000" ucd="" unit="keV" />
                        <Param                          name="light.curve"
value="http://www.agilescienceapp.it/notices/079290_GRB_585679841.69387
3.png" ucd="" />
 </What>
 <WhereWhen>
   <ObsDataLocation>
     <ObservatoryLocation id="AGILE"/>
     <ObservationLocation>
       <AstroCoordSystem id="UTC-FK5-GEO"/>
       <AstroCoords coord_system_id="UTC-FK5-GEO">
         <Time unit="s">
           <TimeInstant>
             <ISOTime>2022-05-30T11:10:32</ISOTime>
           </TimeInstant>
         </Time>
         <Position2D unit="deg">
           <Name1>RA</Name1>
           <Name2>Dec</Name2>
           <Value2>
             <C1>0.0</C1>
             <C2>0.0</C2>
           </Value2>
           <Error2Radius>0</Error2Radius>
         </Position2D>
       </AstroCoords>
     </ObservationLocation>
   </ObsDataLocation>
 </WhereWhen>
 <Description>AGILE-MCAL TRIGGER ALERT NOTICE</Description>
</voe:VOEvent>
```

5.2. Configuration data

The configuration data required to run the AFIS platform are:

1. The connection parameters to the GCN network.
2. The SFTP connections parameters to send scientific results to AFIS.

3. The list of AFIS Team emails.
4. COMET configuration to send STE events.

5.3. Output Data

The AFIS platform generates different types of output:

1. Emails to send notifications to the AFIS Team
2. Results of the time correlation between STE events that are stored in the **Event Database**.
3. Information extracted from the VOEvents received and stored in the **Event Database**.

6. Process View

6.1. Event Management

The workflow, shown in Figure 4, describes the activities performed by the AFIS platform when a science alert is received from the GCN network. In fact, the GCN network sends a notification using the VOEvent data format to all the subscribers to a particular event type (e.g., Fermi-GBM GRBs). The **Event Receivers** receives this information through the COMET service, registered as a subscriber of the GCN network, parses the content of the XML (VOEvent), and stores the data in the **Event Database**. Then, **Event Receivers** checks if inside the database there are other events related to this science alert (e.g., to the same GW event). If this event is new, it sends a notification via email to the AFIS Team.

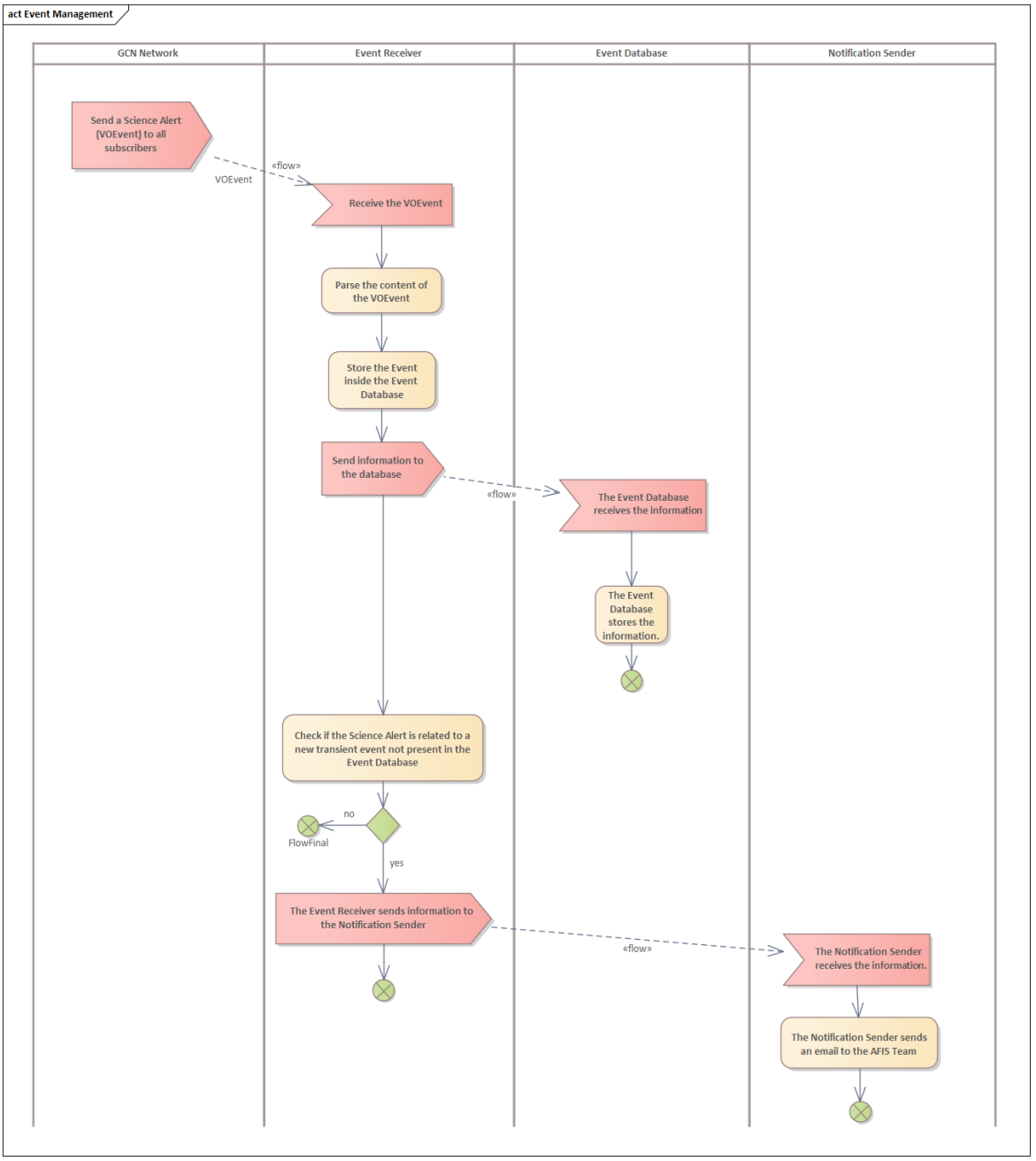

Figure 4: Activity diagrams that describes the workflow when a science alert event is received.

6.2. Sub-threshold event management

The workflow, shown in Figure 5, describes the activities performed by the AFIS platform when a sub-threshold event is received from the RTA pipelines of the AFIS facilities (AGILE and INTEGRAL). When these RTA pipelines detect a transient event that does not have the statistical significance to be shared with the community as a science alert, they send a notification to the AFIS platform sending a VOEvent that is received by **Event Receivers** through the COMET service. The **Event Receiver** parses the VOEvents and stores the information in the **Event Database**. Then, the **Event Receiver** checks if there are other events or sub-threshold events in the database with a time correlation of +- 10 seconds (configurable). If there is a correlation with multiple sub-threshold or standard events, the **Event Receiver** asks the **Notification Sender** to send a notification to the AFIS Team.

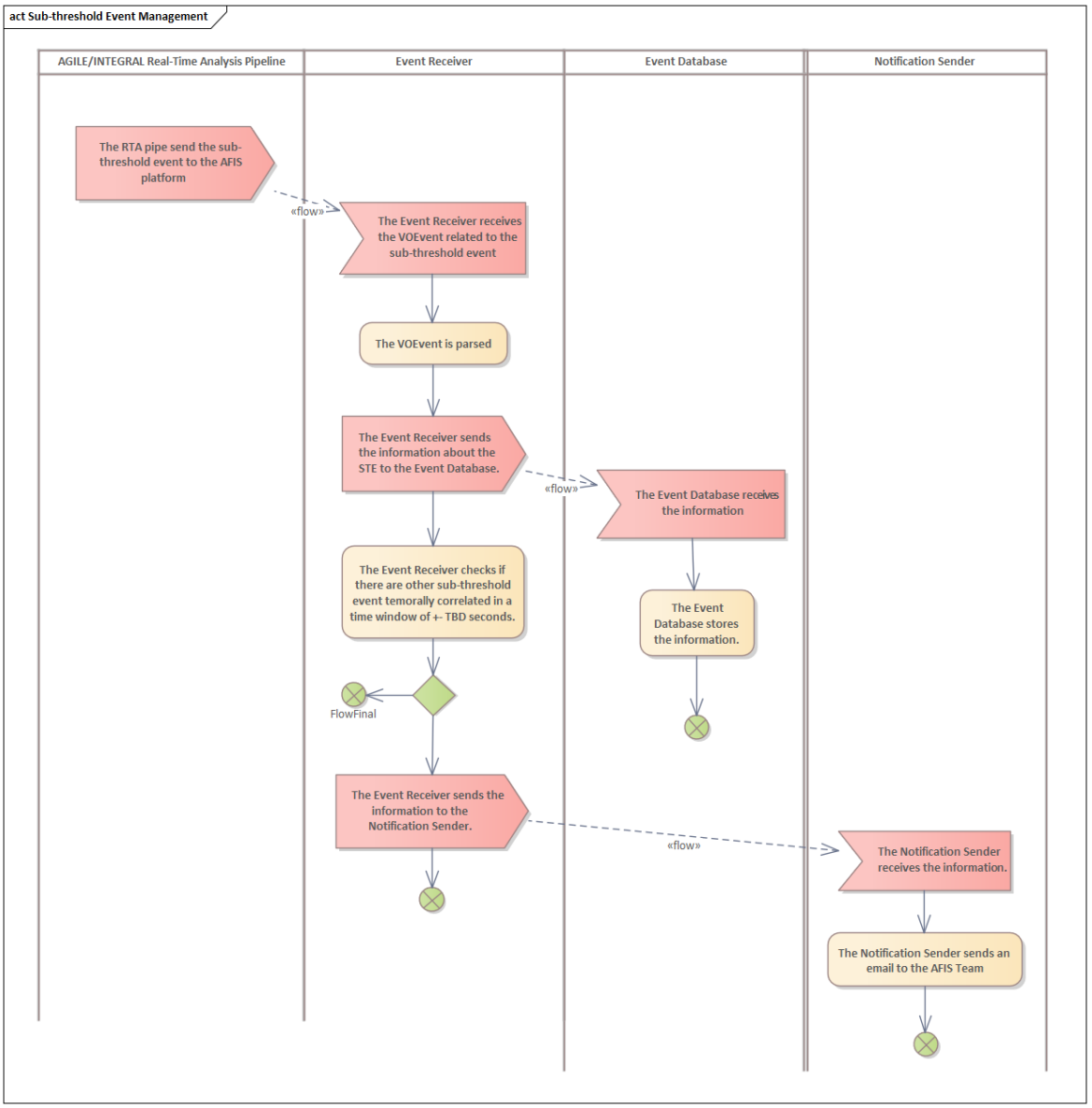

Figure 5: Activity diagrams that describes the workflow when a sub-threshold event is received.

7. Deployment view

The AFIS platform is deployed (Figure 6) as Singularity containers in a dedicated Host Machine that can be a physical machine or a Virtual Machine (VM). We decided to deploy it in separate containers (one for MySQL and Apache and one for COMET) to increase the deployment flexibility. The AGILE and INTEGRAL space missions have their RTA pipelines running inside their servers. These pipelines send scientific results (e.g., sky maps or light curves) to the AFIS platform file system using the SFTP protocol through an Internet connection and VOEvent notifications about transient events through a connection with the COMET service inside the **Event Receiver**.

The AFIS platform receives VOEvents about science alerts from the GCN network through an Internet connection and implements a subscriber inside the Events Receiver.

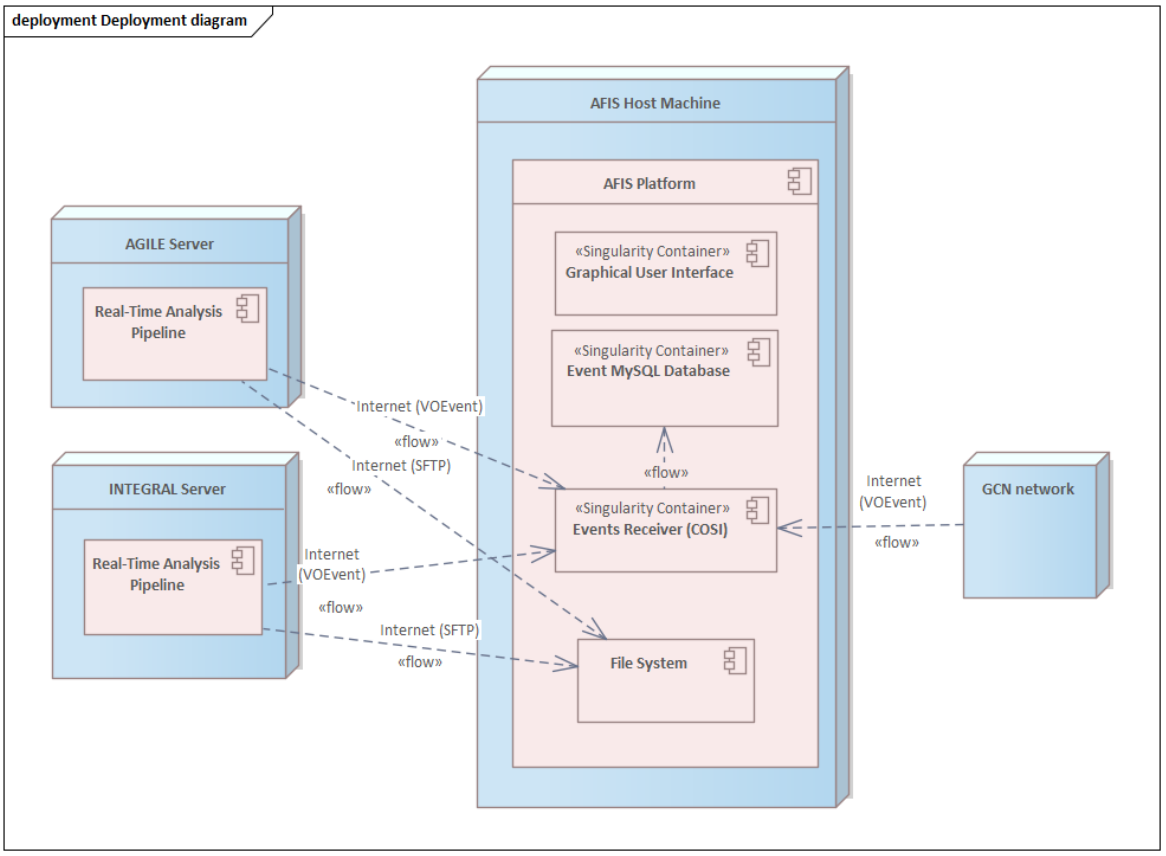

Figure 6: Deployment diagram of the AFIS platform and the system interfaced with it.

AFIS Platform User Manual

Prepared by:	Name:	N. Parmiggiani, A. Addis, J. Rodi	Date:	Jul 31, 2022

Main Authors: N. Parmiggiani, A. Addis, J. Rodi
Contributor Authors: A. Bulgarelli, A. Bazzano.

Table of Contents

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Document History		
Version	***Date***	***Modification***
1.0	Jul 31, 2022	First release of the draft

1. Introduction

AFIS is a collaborative platform that receives external science alerts from e.m., GW and neutrino observatories through the GCN network.

The same collaborative platform allows sharing sub-threshold events, with a joint cross check of time coincidences of sub-threshold events of participating observatories with external science alerts. A more comprehensive joint use of the multiwavelength information is fundamental to 1) unveil features of high-energy processes, 2) increase the rate of detectable sources by accessing lower amplitude events, 3) improve the estimates of the localization and other important characteristics of the source.
This will enable more successful follow-up campaigns of the proposers of the project, and increase the population of sources with identified counterparts.

The AFIS platform provides a dashboard through a web portal that shows a summary of the science alerts, a summary of the results of some AFIS facilities and a list of s events with possible time correlation.

1.1. Purpose

This document describes how the user can interact with the AFIS platform through the web Graphical User Interface (GUI). This GUI allows the user to visualize the results of the AFIS facilities related to the same science alerts or subthreshold events. In addition, the users can upload manually directly from the GUI the results of the analysis.

1.2. Scope

The AFIS system is part of the WP 12.2 of the AHEAD2 project.

1.3. Content

The document is structured as follows:

- Section 2 lists the applicable and reference documents.
- Section 3 describes how the user can interact with the GUI
    - Section 3.1 describes how to visualize the list of science alerts and the correlated results.
    - Section 3.2 describes how to visualize the list of sub thresholds events and the correlated results.
    - Section 3.3 describes how to upload results manually using the GUI
    - Section 4 describes how to send results to the AFIS platform using an SFTP connection.

- Section 5 describes how to send STE events through the COMET client.

1.4. Abbreviations and acronyms

AFIS	AGILE, Fermi, Integral, Swift
GCN	Gamma-ray Coordinates Network
GUI	Graphical User Interface
RTA	Real-Time Analysis
SFTP	SSH File Transfer Protocol
VM	Virtual Machine
XML	Extensible Markup Language

2. Applicable and reference documents

2.1. Applicable documents

[AD1] AFIS Platform Use Cases. Issue 1.0, 15-Sep-2021.
[AD2] AFIS Platform Software Detailed Design. issue 1.0, 25-Apr-2022.

2.2. Reference documents

[RD1] Luigi Piro et al. *"Integrated Activities for the High Energy Astrophysics Domain."* Call: H2020-INFRAIA-2018-2020. Topic: INFRAIA-01-2018-2019, Proposal number: 871158 Proposal acronym: AHEAD2020.

3. Web Graphical User Interface

3.1. Visualize the list of science alerts

Figure 1 shows the home page of the GUI, where the user can visualize the list of science alerts received from the GCN network and stored in the AFIS database.

The table presents the following information:

1. The instrument name that generated the science alert
2. The trigger id reported in the VOEvent
3. The sequence number indicates if the notice is the first related to a particular event or an update (i.e., this usually happens with GW).
4. The event_id (only for GW events)
5. The trigger time in UTC.
6. The notice time in UTC indicates when the AFIS platform receives the notice.
7. The event type: GRB, neutrino, FRB, and information about the GW class probability (e.g., terrestrial, BNS or BBH).
8. Finally, the table has two buttons. The first button opens the web page where the user can visualize all the scientific results collected by the AFIS platform related to an

event. The second one opens the upload page, where the user can manually upload results such as sky maps, light curves, and more.

The table has a “search field” that can be used to find a specific event using the trigger id or other parameters.

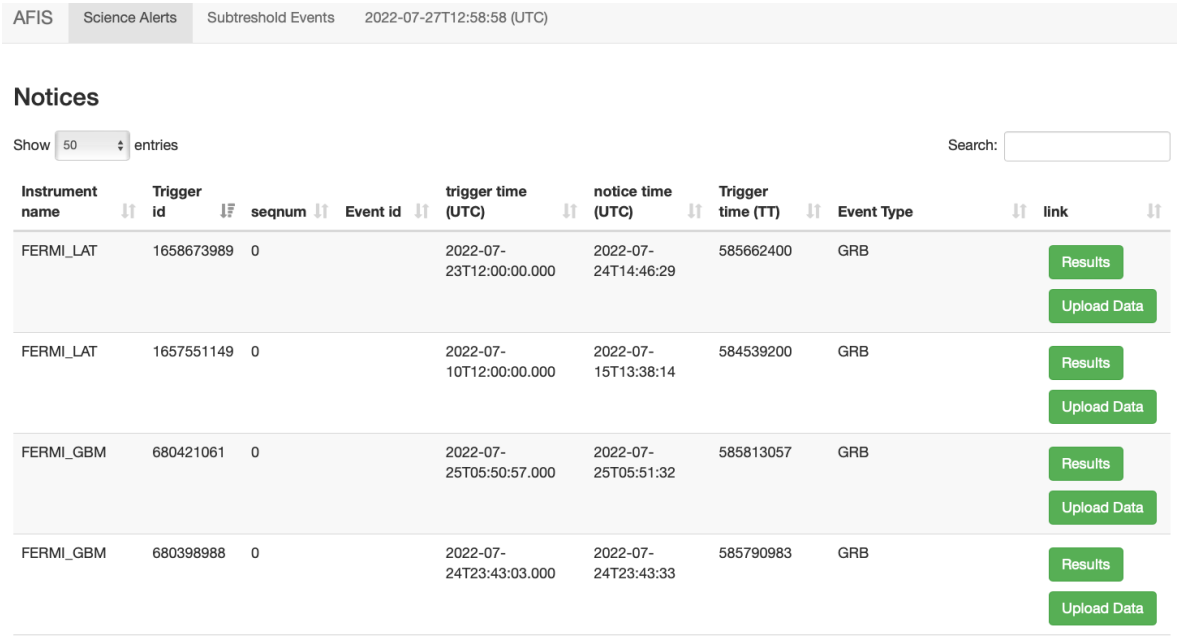


Figure 1: Table showing the list of science alerts received from the GCN network.

3.2. Visualize the list of subthreshold events

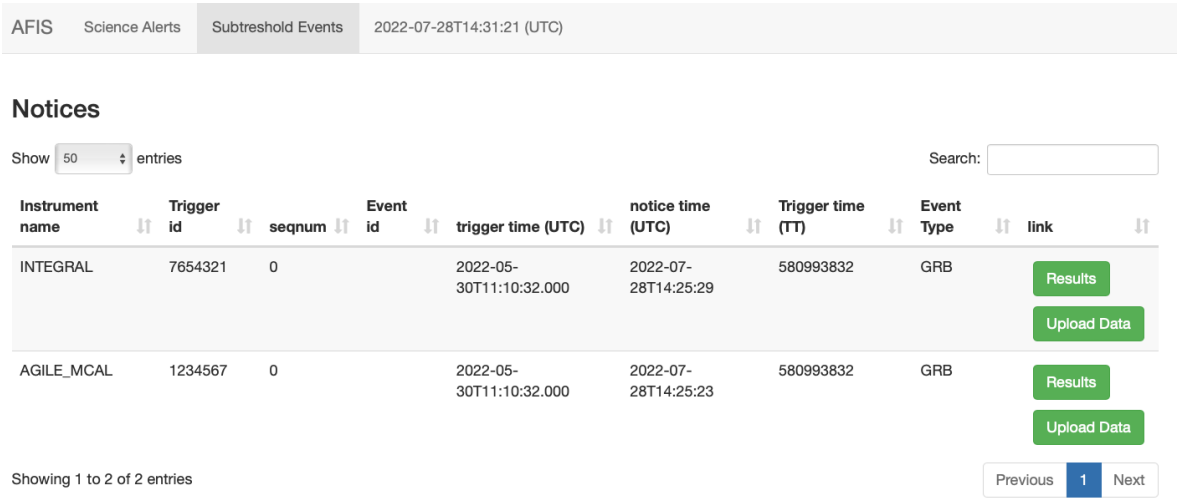


Figure 2: Table showing the subthreshold events.

3.3. Upload results manually

Figure 3 shows the web page where the user can manually upload the results produced by the facilities' pipelines. This page is related to a specific event and an automated backend software links the uploaded results with that event. After the upload, the users can visualize the results in the detail page of that event Figure 5.

In order to upload results, the user must choose the mission that generated the results as shown in Figure 4 (AGILE, FERMI, INTEGRAL or SWIFT). After that, the user can select the file from its local directories, add a text comment and upload the results to the AFIS platform. The file must have one the following formats: pnj, jpg, or jpeg. This operation is password protected and only authorized users can upload results.

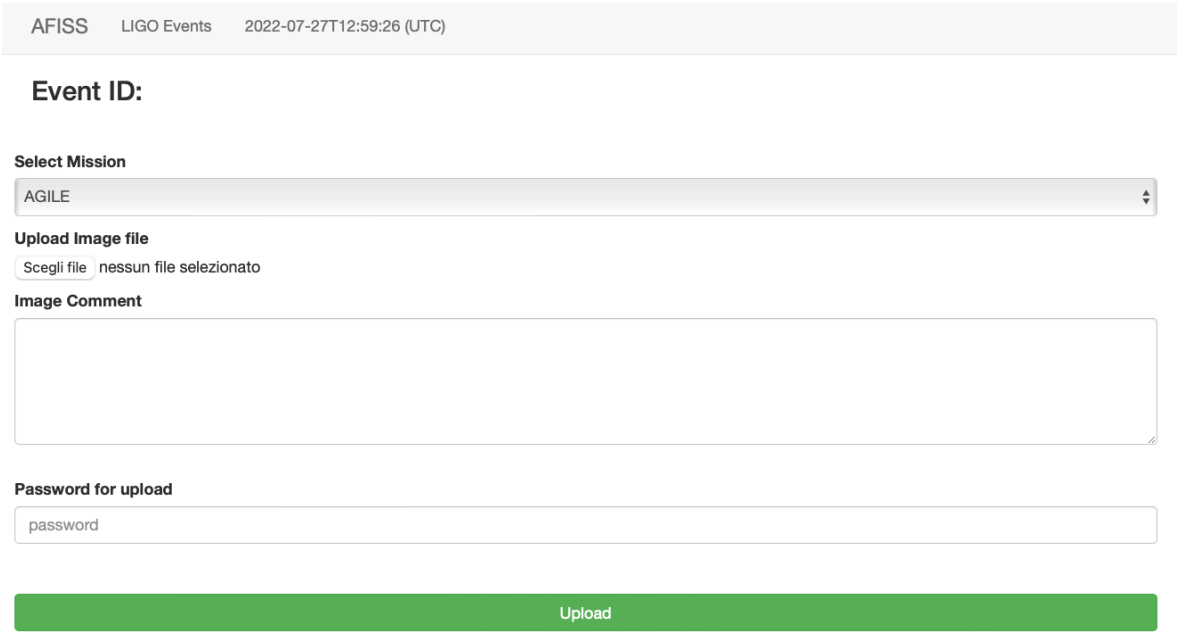


Figure 3: Form to manually upload results such as sky maps and light curves.

Figure 4: Selection of the mission that generated the results that the user is uploading.

3.4. Visualize the detail page of an event

The user can use the green button “Results” in the data tables to open a web page taht shows detailed results about the event selected. Figure 5 shows an example of this detail

page related to a LIGO_TEST science alert. The page contains AGILE and INTEGRAL results.

The first information shown is about the event: instrument name, trigger ID, sequence number and trigger time in UTC format.

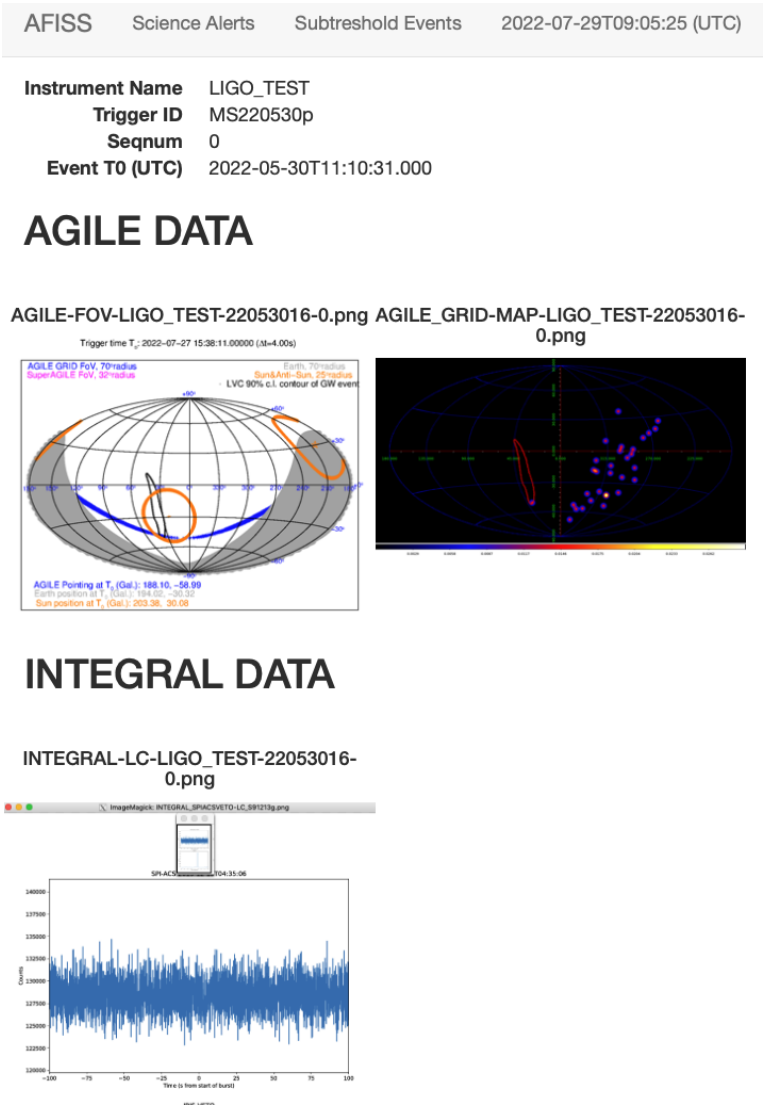
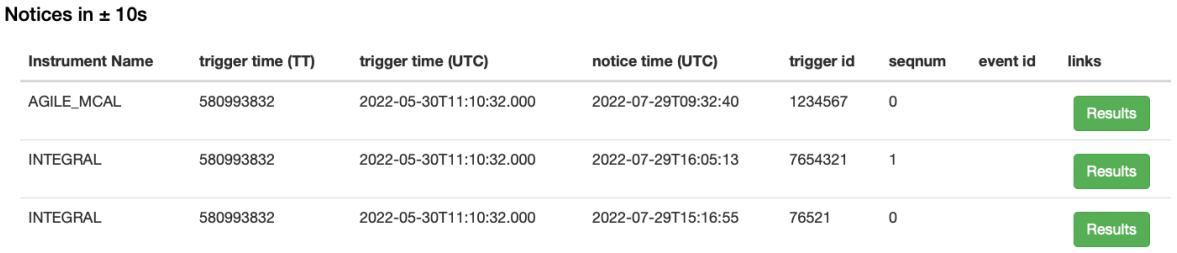


Figure 5: Web page with the results (AGILE and INTEGRAL) related to a LIGO_TEST event.

The next block shows a table (Figure 6) that indicates if this event has a time correlation with other events in a time window of +- 10 seconds.

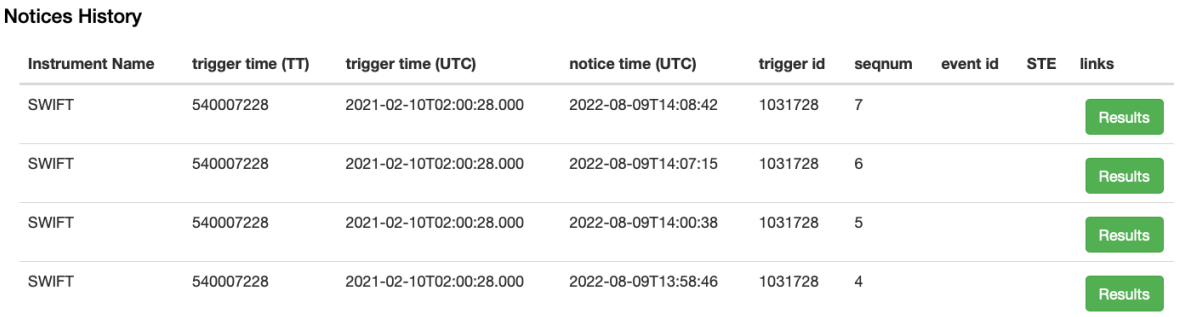


Notices in ± 10s

Instrument Name	trigger time (TT)	trigger time (UTC)	notice time (UTC)	trigger id	seqnum	event id	links
AGILE_MCAL	580993832	2022-05-30T11:10:32.000	2022-07-29T09:32:40	1234567	0		Results
INTEGRAL	580993832	2022-05-30T11:10:32.000	2022-07-29T16:05:13	7654321	1		Results
INTEGRAL	580993832	2022-05-30T11:10:32.000	2022-07-29T15:16:55	76521	0		Results

Figure 6: Table that shows the time correlation between the selected event and other events inside the AFIS database.

At the end of the page there is the table (Figure 7) that lists all the history of notices sent by the facility from the GCN network related to the target event.



Notices History

Instrument Name	trigger time (TT)	trigger time (UTC)	notice time (UTC)	trigger id	seqnum	event id	STE	links
SWIFT	540007228	2021-02-10T02:00:28.000	2022-08-09T14:08:42	1031728	7			Results
SWIFT	540007228	2021-02-10T02:00:28.000	2022-08-09T14:07:15	1031728	6			Results
SWIFT	540007228	2021-02-10T02:00:28.000	2022-08-09T14:00:38	1031728	5			Results
SWIFT	540007228	2021-02-10T02:00:28.000	2022-08-09T13:58:46	1031728	4			Results

Figure 7: Table that shows the history of notices received by the GCN network related to the target event of the detail page.

4. Send results through SFTP connection

The automated pipelines of the AFIS facilities can upload results to the AFIS platform using an sftp connection using the following command changing the [filaname].

The format for the file name must be:
instruments_results-results_type-alert_instrument-triggerid-seqnum.png

- instruments_results: the name of the facilities that is sending the results (e.g., AGILE or INTEGRAL)
- results_type: a name to identify the analysis type (e.g., LC or SKYMAP)

- alert_instrument: the name of the facility that triggered the science alert
- triggerid: ID of the science alert
- seqnum: sequence number of the notices related to a target event (e.g., LVC sends several notice related to the same event with updates)

Example: INTEGRAL-LC-LIGO_TEST-MS220530p-0.png

```
sftp afiss_ftp@afiss.iasfbo.inaf.it:/files <<< $'put [filename]'
```

NOTE: to use the sftp connection the system must be configured with an ssh public key

5. Send Subthreshold (STE) events using VOEvents

The AFIS platform can receive STE events from the AFIS facilities through the COMET framework.

The installation tutorial for the COMET library can be found here: https://comet.transientskp.org/en/stable/installation.html.
The procedure to send VOEvents related to STE is described in this web page: https://comet.transientskp.org/en/stable/usage/publisher.html

The VOEvent format must follow specific rules that are defined in the AFIS Software Design Document [AD2].