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The AGILEScience Mobile Application for the AGILE Space Mission

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ABSTRACT

AGILE is a space mission launched in 2007 to study X-ray and gamma-ray phenomena through data acquired by different payload instruments. The AGILE Team developed an application called AGILEScience that allows to visualize information about the AGILE space mission from mobile devices, such as smartphones and tablets. The AGILEScience application can be downloaded freely for iOS and Android devices.

Beside sharing information about the AGILE space mission with the public for outreach purposes, similarly to what other applications do, the AGILEScience app offers some new and unique features in gamma-ray astrophysics: (i) it gives public access in nearly real-time to the sky view of a gamma-ray satellite for the first time, (ii) it interacts with the AGILE remote gamma-ray data storage and analysis system, allowing data analysis to be sent and results to be visualized, and (iii) it allows the AGILE Team to access a password-protected section of the app to view detailed AGILE pipeline results and submit advanced analyses. The last two features are critical to allow remote and easy access to the results of the AGILE automated pipelines.

In particular, the ability to visualize results and execute manual data analysis from mobile devices is key during the follow-up of transient events and to easily monitor the satellite status via smartphone.

1. Introduction

AGILE (Astrorivelatore Gamma ad Immagini LEggero - Light Imager for Gamma-Ray Astrophysics) is a space mission of the Italian Space Agency (ASI) devoted to high-energy astrophysics and launched on April 23, 2007 (Tavani et al., 2008, 2009). The AGILE payload consists of the Silicon Tracker (ST), the SuperAGILE X-ray detector, the CsI(Tl) Mini-Calorimeter (MCAL), and an AntiCoincidence System (ACS). The combination of ST, MCAL, and ACS composes the Gamma-Ray Imaging Detector (GRID).

In multi-wavelength (MWL) and multi-messenger (MM) astronomy (Mészáros et al., 2019), one of the primary objectives of the AGILE space mission is to detect transient events and disseminate them to the scientific community, enabling other facilities to observe the same physical phenomena through various messengers, including neutrinos, gravitational waves, and electromagnetic waves, across different wavelengths. On the other hand, it is important to follow up the science alerts received by other facilities and perform analyses of AGILE data searching for counterparts.

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The AGILE Team developed a real-time analysis system (RTA) (Bulgarelli, 2019; Parmiggiani et al., 2023), partially based on the RTApipe framework (Parmiggiani et al., 2022), which performs prompt analyses on data acquired by the satellite and reacts to external science alerts.

In this context, the AGILE Team developed a mobile application for both the iOS[1] and Android[2] operating systems, which is available for free download on mobile devices such as smartphones and tablets.[3].

The AGILEScience application has three main distinctive features:

1. It gives public access in nearly real-time to the sky view of a gamma-ray satellite for the first time.
2. It interacts with the AGILE remote gamma-ray data archive and analysis system, allowing the public to submit data analyses and view results directly from an app for the first time in gamma-ray astrophysics.
3. It allows the AGILE Team to access a password-protected section of the app to visualize the detailed results of the AGILE RTA pipelines and submit 4advanced analyses.

In addition, as with other astronomy applications, this app is used to share information about the space mission with the public. In particular, the application shows the

[1]https://apps.apple.com/it/app/agilescience/id587328264
[2]https://play.google.com/store/apps/details?id=com.agile.science&gl=IT
[3]https://apps.apple.com/it/app/agilescience/id587328264

main scientific AGILE results, images, and videos about the AGILE construction and launch campaign. It also allows users to track the location of AGILE in real time as it orbits the Earth.

In Section 2 we present a comparative overview of other existing astrophysical applications for mobile devices, emphasizing the novelty of the AGILEScience app. Section 3 presents the overall architecture of the application from the user's point of view. It describes in detail each section of the application and related screenshots taken from the iOS version. Section 4 describes the backend system that supports the application. In section 5 we present how we implemented the AGILEScience application for iOS and Android operating systems and how the application is distributed in the official distribution channels of the two environments. Conclusions are given in section 7.

2. Mobile applications for astrophysics

In Schaaff and Jagade (2015), the authors describe that thanks to the rapid development of mobile technologies (smartphone and tablet) and also the improvement of the bandwidth of mobile networks (e.g., 4G), mobile devices have become significant tools that everyone has in the pocket. These mobile devices can be used to access data via a browser, but it is also possible to develop native applications to exploit the device's full capabilities. Finally, the authors conclude the manuscript by stating that the future of Virtual Observatory (Borne, 2013) is in the pocket.

In recent years, numerous mobile applications for iOS and Android operating systems have been developed within the astrophysical domain. Most of them are educative applications for students and the general public dedicated to the solar system or sky views to identify stars, constellations, and planets. Here, we will focus on two types of applications that have been developed for high-energy astrophysics in the context of Multi-Messenger (MM) and Multi-Wavelength (MW) astronomy (Mészáros et al., 2019).

The first type of application aims to notify the users about transient events in the context of the MM and astronomy. These applications have a crucial role in the astrophysical community. Indeed, receiving notifications about transients quickly and in the shortest time possible is essential to execute a good follow-up of the transient events with other facilities. Thus, the advantages of receiving notifications on a mobile device are evident. The Astro-COLIBRI platform (Schüssler et al., 2023), developed for real-time MM astrophysics, manages transient events such as Gamma-Ray Bursts (GRB) and Fast Radio Bursts (FRB) and notifies the users through several clients. The users can also receive notifications using iOS and Android mobile applications.

Chirp[4] and GW Events[5] are two mobile applications developed respectively for Android and iOS devices with the aims to notify gravitational waves events. They offer several features to configure the notifications that can be used to fit the applications with the needs of a particular context.

The second type of application, like the AGILEScience app described in this paper, is developed to connect the users with the data of a space mission, visualize the results, and provide other information about the satellite, such as the orbit. The Fermi space mission (Atwood et al., 2009) presented a mobile application for Android and iOS devices (Stephens, 2013) that allow users to access high-level public data such as light curves (not sky maps) from the Fermi Science Center[6] and from other sources such as the Astronomer's Telegram (ATel) website[7] and the General Coordinates Network[8] (GCN). Finally, the application shows to the users the high-level scientific results related to light curves of routinely monitored gamma-ray sources.

A mobile application was developed for the Swift space mission (Gehrels et al., 2004) to list and map recently discovered gamma-ray-bursts by the NASA Swift X-ray mission, including optical images and data from the Swift's detectors.

Unfortunately, both these high-energy astrophysics applications are no longer available in the official distribution channels for Android and iOS at the time of writing.

3. AGILEScience application structure

The main navigation bar appears at the bottom of the app screen in the iOS version and at the top left in the Android version. It includes the following sections:

1. Home: This is the main page displayed when the user opens the app.
2. News: This window lists the latest news about the scientific results of the AGILE space mission.
3. Gallery: In this section, it is possible to visualize images and videos about AGILE, its construction, and its launch campaign.
4. Top: This section lists the main scientific results achieved by the AGILE Team.
5. More: This section provides access to various resources related to AGILE, including a list of papers, the ATel website, GCN publications, a real-time map showing the satellite's position relative to the Earth's surface, and a password-protected section for the AGILE Team.

3.1. Home

The Home window (Figure 1 - left panel) is the first one that the user visualizes at the application startup from the mobile device. It shows an image of the Crab Nebula and of the AGILE satellite. We decided to use the Crab Nebula as the first image of the app since AGILE won the Bruno Rossi Prize in 2012 detecting the gamma-ray variability of this source (Tavani et al., 2011), one of the most important discoveries of the AGILE space mission.

Through this window the user can access several buttons:

[4] https://play.google.com/store/apps/details?id=org.laserlabs.chirp

[5] https://apps.apple.com/us/app/gravitational-wave-events/id1441897107

[6] https://fermi.gsfc.nasa.gov/ssc/

[7] https://astronomerstelegram.org/

[8] https://gcn.nasa.gov/

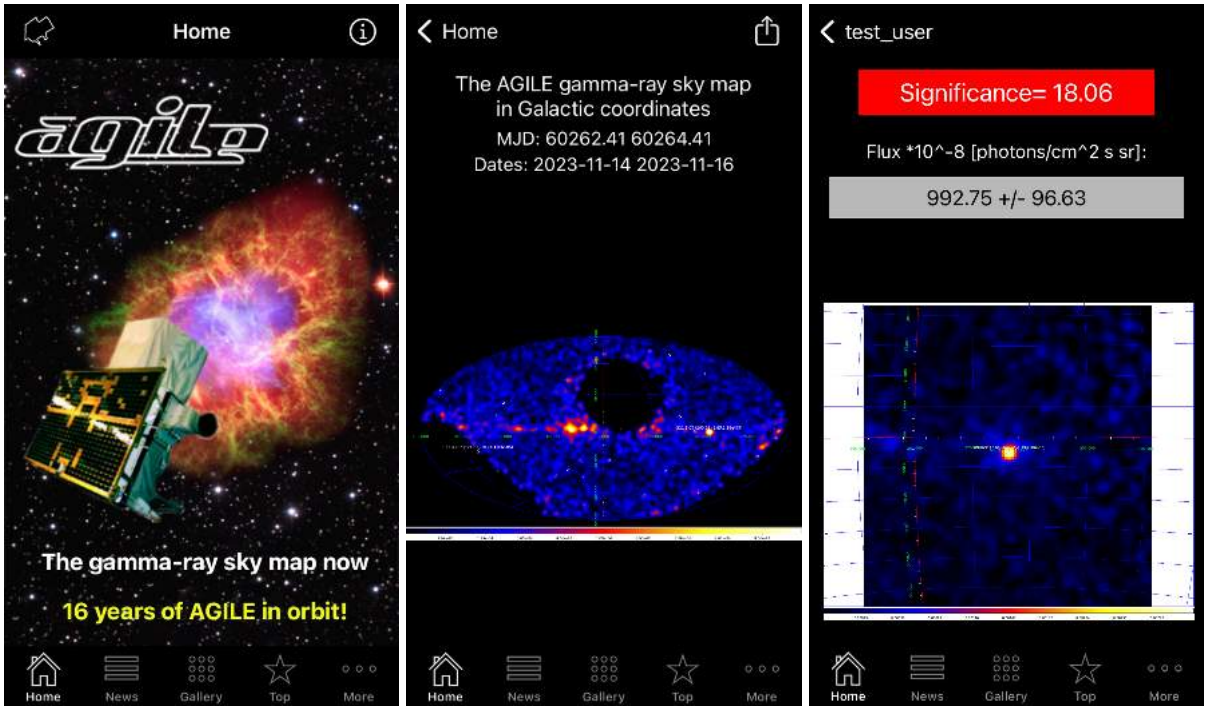

Figure 1: Left panel: Home page of the application. This is the first view that the user visualizes after the application's startup. Central panel: Sky map showing the gamma-ray sky map as seen by AGILE, updated with the lateset acquired data. Right panel: Example of results obtained with the public manual analysis feature.

- The top navigation bar has two buttons in the iOS version and one button in the Android version. In the iOS version the left one opens a new window with a detailed description of the AGILE satellite, while the right one opens a window with the acknowledgment for the app. In the Android version the two contents are displayed in the same window.
- The "The gamma-ray sky map now" text is a button that opens a gamma-ray sky map (Figure 1 - central panel) generated from AGILE data at every ground contact of AGILE about every 90 minutes (provided that there are no anomalies in the data acquisition schedule).
- The "16 years of AGILE in orbit!" text is automatically updated and shows the number of years since AGILE was launched (16 years at the moment of writing).

3.1.1. The real-time gamma-ray sky map

This window shows the gamma-ray sky map (Figure 1 - central panel), with the Galactic coordinate system and the AITOFF projection, generated by the AGILE automated analysis system in about 30 to 50 minutes since the data downlink (Bulgarelli, 2019) using the latest available data. AGILE has the fastest RTA system to generate gamma-ray results above 100 MeV among the gamma-ray space missions. The view shows information about the integration time in MJD and UTC time formats.

In the top navigation bar of the iOS version, a sharing button opens a selection menu for sharing the image through several channels (mail, social networks, messages etc.). In addition, the iOS version allows the user to open a historical view that presents a sequence of past sky maps. The user can scroll through the gallery to visualize older ones. This feature is also useful to monitor the gamma-ray sky and to follow up on transient events. Finally, the settings button can be used to reload the view or delete the history to free memory space on the device.

In the latest iOS version, the general user can also access some of the additional features originally developed for the AGILE Team members (see also Section 2.5.1), such as the manual analysis section, which allows to open a window where to perform standard analysis on AGILE data Bulgarelli et al. (2012), by submitting jobs to the AGILE remote server and then visualizing the results on the app (Figure 1 - right panel). To execute the analysis, the user has to define the target position and the chosen time window. We are currently testing this and other new features in the iOS version, then we plan to implement them also in the Android version. This is a unique feature of the AGILEScience app for high-energy astrophysics.

3.2. News

The News section (Figure 2 - left panel) shows a list of news related to AGILE, obtained from two different sources. Depending on the language setting, the app gathers the list of recent news from the Media INAF (National Institute for

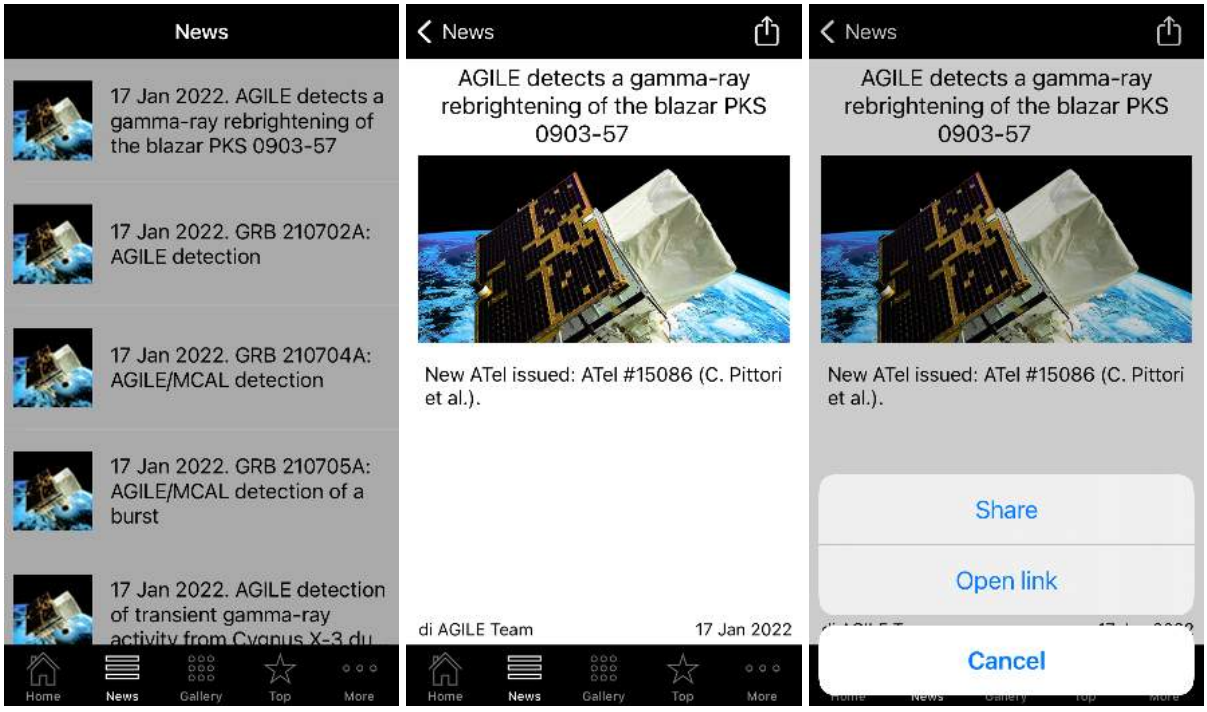

Figure 2: Left panel: section that lists the news related to the AGILE space mission. Central panel: news details with a full-text description. Right panel: a window to share the news through social networks, email, or messages.

Astrophysics) website[9] (Italian) or to the ASI ASI Space Science Data Center (SSDC) website [10] (English). In fact, the AGILEScience application supports both languages, Italian and English.

Each news article is presented with a title and a thumbnail image. When a user clicks on a news article, the app opens a new window (Figure 2 - central panel) displaying its details, a brief description, and a larger image. It is possible to share the news and perform other actions through the button on the right of the top navigation bar (Figure 2 - right panel).

3.3. Gallery

The Gallery section (Figure 3 - left panel) displays videos and pictures taken during AGILE's development and launch campaign. Additionally, it includes interviews with AGILE researchers and maps showcasing important scientific results.

When the user opens a sub-section, e.g., the launch campaign, the app shows a gallery of previews (Figure 3 - central panel) that the user can touch to open on full-screen (3 - right panel). The full-screen images can be zoomed in through the touch screen. It is possible to open a window with a caption using the info button in the right part of the top navigation bar. This behavior is the same for all galleries.

3.4. Top

This section of the app shows the main scientific discoveries of the AGILE space mission. The layout of this section is the same as the News section (Figure 2). The AGILE team manually updates the list when relevant scientific results are published. As for the news section, it is possible to open the details of the results. It is possible to share the results and perform other actions using the button on the right part of the top navigation bar.

3.5. More

This menu of the app (Figure 4 - left panel) shows a list of buttons to open additional sections:

- Papers: this window (Figure 4 - central panel) lists all the papers related to the AGILE space mission. The list of papers is updated automatically by querying the NASA/ADS [11] archive as described in section 4.
- ATel and GCN: this button opens the list of telegrams present on ATel website or the GCN Circulars related to the AGILE space mission. The lists are updated with a periodic automated procedure using the NASA/ADS archive.
- Satellite Position: this button opens a map that shows the AGILE satellite position projected over the Earth (Figure 4 - right panel), which is updated automatically every second.
- AT Reserved: this section is password-protected and accessible only to the AGILE Team.

[9] https://www.media.inaf.it/
[10] https://agile.asdc.asi.it/news.html
[11] https://ui.adsabs.harvard.edu/

Figure 3: Left panel: main menu for the gallery section, the user can select different content such as videos or pictures taken during the AGILE development and launch campaign. Central panels: the content of the gallery is shown in a grid of images. Right panel: the user can select one picture to visualize it in full-screen mode, zoom, and obtain related information using the right button in the top navigation bar.

3.5.1. AGILE Team reserved area

This section of the application is reserved to the AGILE Team. The access is password-protected and, inside this section, the user can visualize the results of the automated AGILE software, monitor the AGILE status, and submit manual analysis to the remote server. The AGILE team will consider making some of the restricted functionality available to the general public at the end of the post-operative phase of the mission (December 2025).

There are three subsections:

- Monitoring: this window shows a list of monitoring information about the AGILE satellite, such as the status of the data acquisition flow.
- AITOFF: This button opens a section where the user can visualize the results of automated analysis software that performs analyses on the AGILE/GRID instrument data (Bulgarelli et al., 2014). The results of this software are sky maps (in Galactic coordinates and Hammer–Aitoff projection) with different integration times, and they are updated each time the system receives new data from the satellite. The sky map with two days of integration time is the same map publicly shown in the app Homepage. The user can zoom in on the image via a touch screen. The grey bar allows the user to select the integration times, which are provided above the map in MJD format. The button on the right of the top navigation bar allows the user to share the sky maps through different services (e.g., Messages and Email). This feature can be used to share the results with the AGILE Team and obtain feedback from other members.
- Scientific analysis: this section can be used to submit manual scientific analyses to the remote AGILE server, where they are executed in a virtual environment containing the AGILE data and Science Tools. Finally, the user can visualize the results of the analyses using the app. This tool is very useful during the follow-up of transient sources since it allows the AGILE Team to perform analyses from their mobile devices, i.e., if they are away from their workstation. This reduces the reaction time of the AGILE Team to science alerts. It is also possible to use the button on the right of the top navigation bar to submit new analyses starting from existing ones but with different analysis parameters (Figure 5 - left panel). The results of the analyses, such as sky maps (Figure 5 - central panel) or textual information (Figure 5 - right panel), are visualized directly inside the application.

4. AGILEScience website and backend

Figure 6 shows the high-level schema of the AGILEScience interactions with other services to retrieve information and execute analyses.

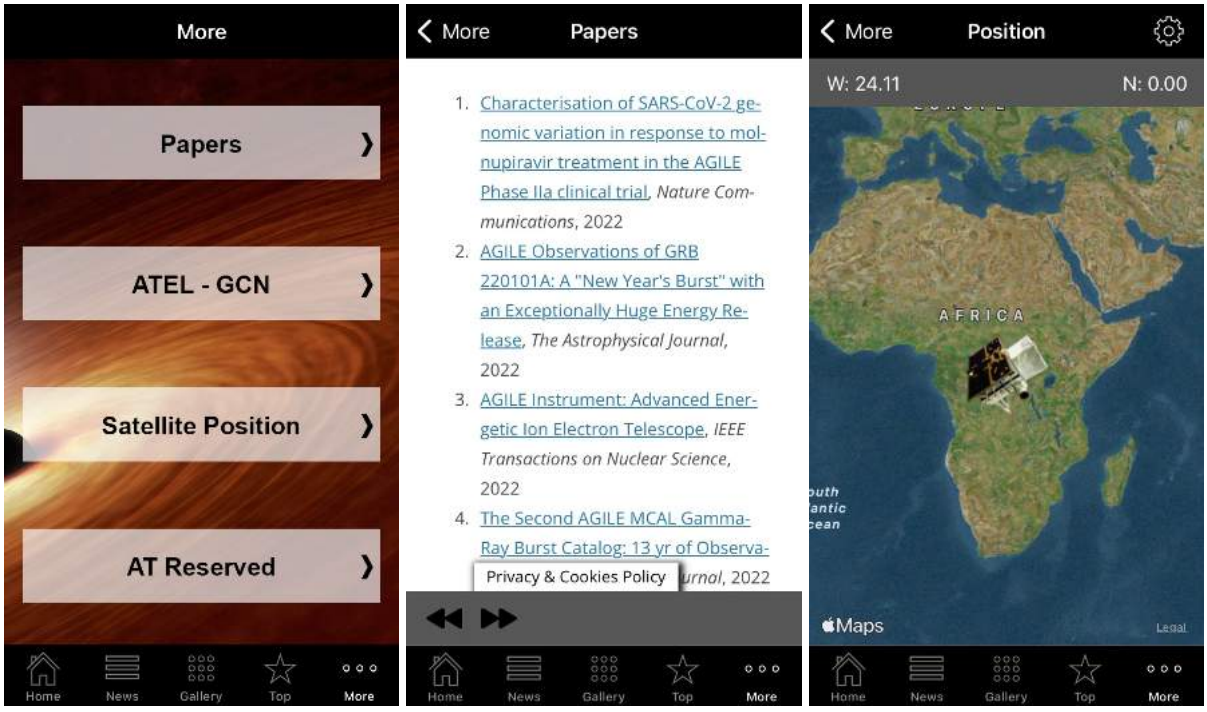

Figure 4: Left panel: List of buttons that open sections with additional information about the AGILE Space mission. Central panel: list of papers related to the AGILE mission. Right panel: the position of the satellite projected over the Earth's surface.

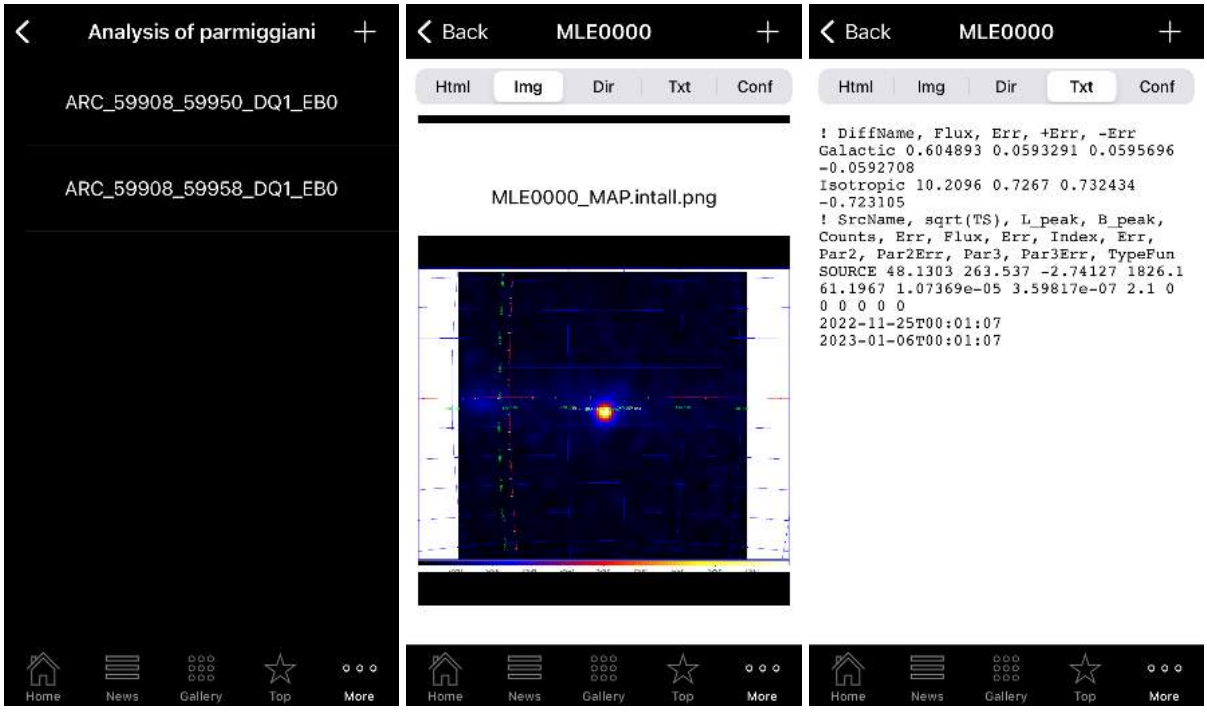

Figure 5: Left panel: List of analyses submitted by the user to the remote server. Central panel and right panel: results of the analyses, such as sky maps or texts.

The application retrieves information from two remote web servers through HTTP[12] connection. One is hosted on a private hosting provider, independent and external to the INAF computing centers to grant high availability of the service through redundancy. Indeed, at least one of the two should be always available. The AGILE Team manages the second server hosted in the INAF computing center.

[12]https://httpwg.org/specs/

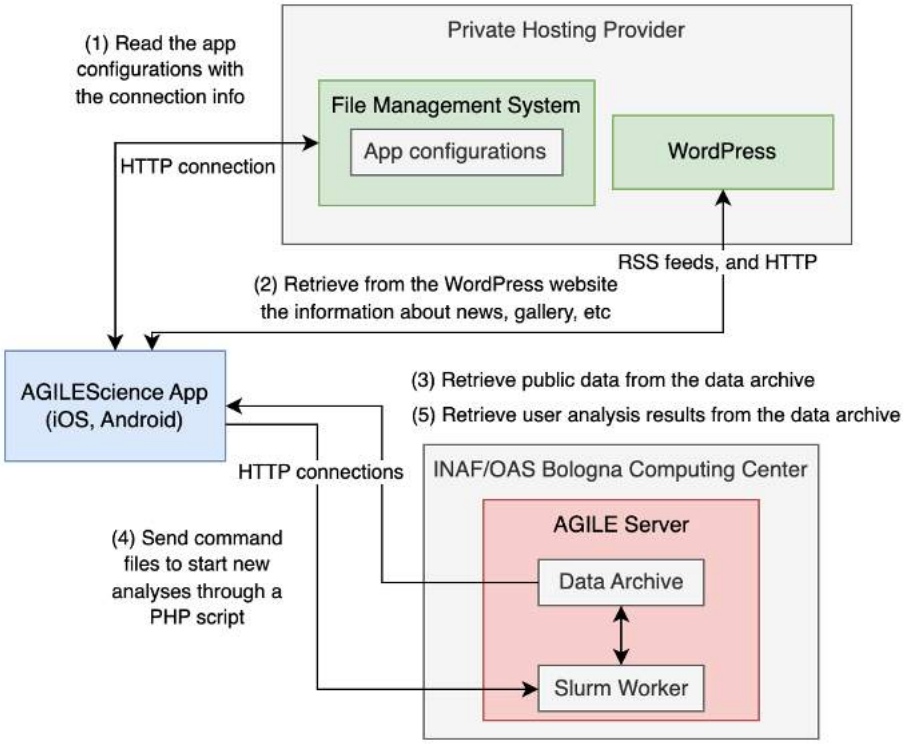

Figure 6: Overview of the AGILEScience app interactions with other platforms. When the app is opened, it collects the configurations with connections for other servers, such as the AGILE Server, from the private hosting provider (1). When the user opens one of the app's sections, the app downloads public data from the WordPress platform (2). Part of the public data is downloaded from the AGILE Server (3). When the user submits an analysis to the AGILE Server, the app sends a file to the server via HTTP connection (4). The results are stored in a Data Archive, and the app can show these results to the user who executed the analysis (5).

We used the private hosting provider to deploy a website developed with the WordPress[13] platform and to store configuration files used by the application.

The first step performed by the AGILEScience application at startup is to read a configuration file from the private hosting provider using an HTTP connection to acquire the connection address for the AGILE server (Figure 6 - step 1). In case the main AGILE pipeline is not reachable (e.g., the INAF computing center is under maintenance), we can reroute the application requests to a backup machine deployed in the SSDC computing center in Rome. In addition, from this configuration file, we can define the minimum required version of the application that is compatible with the backend system. Thus, we can force the users to update the application to avoid incompatibilities.

The application retrieves public information (e.g., images and texts) from the WordPress website through HTTP connections (Figure 6 - step 2). The WordPress platform is an open-source web content management system and can be customized with several themes and plugins. We chose to use this platform because it enables us to utilize available plugins to automatically populate the platform with content from external sources such as RSS feeds or JSON feeds. Additionally, it provides straightforward storage and management of content (including pictures and text). The support web platform retrieves feeds from the Media INAF website[14] and the ASI SSDC news related to AGILE[15]. The AGILEScience application can show the information both in Italian and English. The language selection also determines the feed, since the contents are not always available in both languages from the same source. Additionally, users can access the WordPress website at www.agilescienceapp.it, which contains the same public sections as the app. Figure 7 shows the homepage of this website in English, also available in Italian.

The mobile application downloads public and private information from the web server deployed in the INAF/OAS Bologna computing center, where the AGILE RTA pipelines generate scientific results. The AGILE RTA results are stored in the AGILE server data archive as images, text, and HTML tables. Then, the application can visualize these results through an HTTP connection to the AGILE server (Figure 6 - step 3). The results reserved only to the AGILE Team can be visualized in the password-protected section of the application but the procedure to retrieve them from the remote server is the same as the public data.

[13] https://wordpress.com/it/

[14] https://www.media.inaf.it/tag/agile/

[15] https://agile.ssdc.asi.it/news.html

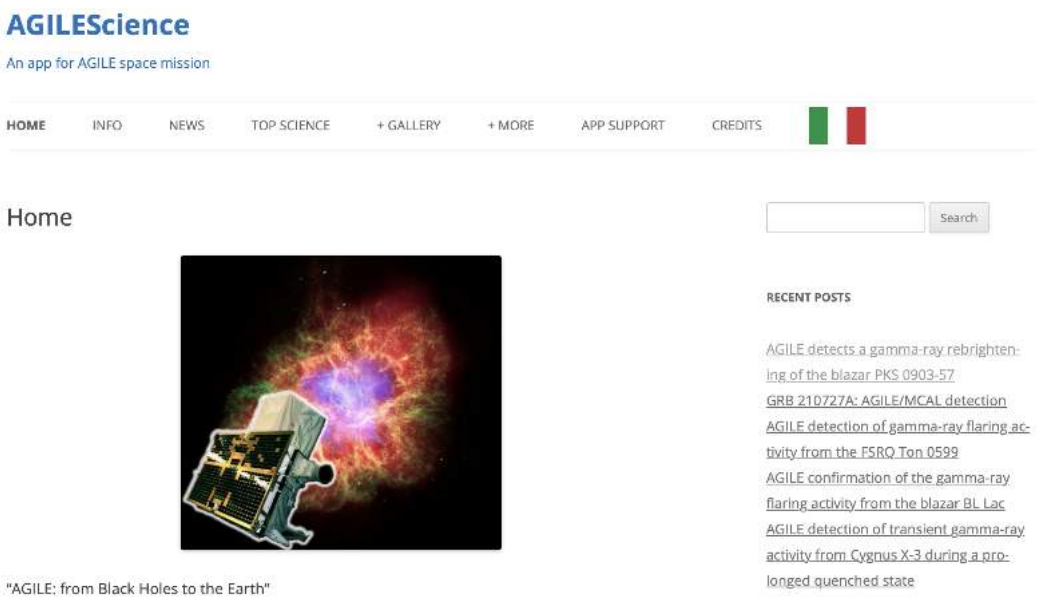

Figure 7: Homepage of the AGILEScience Wordpress website.

One of the features available to the AGILE team is to submit new analyses on the remote AGILE server (Figure 6 - step 4) by uploading a configuration file prepared directly within the app, using an HTTP connection with a PHP[16] program, which receives the configuration file and starts the analysis on the server. The configuration file contains the parameters required to execute the scientific analysis with the science tools installed on the remote server. The application has a dedicated view containing a form that the user can compile with the required information, such as the sky position and the time interval of interest for the analysis. When the file is uploaded, the PHP program writes it in a dedicated directory on the server. An automated procedure reacts when a new configuration file is available and submits the analysis to the Slurm[17] workload manager. Slurm is an open-source, fault-tolerant, and highly scalable job scheduling system. More details about Slurm can be found in Parmiggiani et al. (2022). When the analyses are completed, the results are available in the server's file system, and the application can visualize them using HTTP connections (Figure 6 - step 5).

5. Implementation and Distribution

We developed two versions of the application for iOS (for both smartphones and tablets) and one for Android using the official development tools, Xcode[18] and Android Studio[19], respectively. The programming language used to implement the iOS application is Objective-C, a general-purpose, object-oriented programming language officially adopted for iOS application development. On the other hand, for the Android application, the official programming language is Java[20].

This project started with the development of the app for iOS first. Then, the AGILE team decided to develop an Android version. For this reason, we did not take into account multi-platform applications at that time but decided to implement the application using the standard development tools provided and native programming languages. In addition, we considered that multi-platform applications can have a shorter lifetime than the official iOS and Android development platforms.

The applications can be freely downloaded from the official application stores of the two platforms. We released the first version of the iOS application in December 2012 and the first version of the Android application in August 2014. Over the years, we have maintained and updated the applications, adding new features and ensuring compatibility with new generations of devices and mobile operating systems.

5.1. Download statistics and User Feedback

The users downloaded the Android version of the app 3180 times. The number of downloads was almost constant over the years, with some peaks that can be motivated by the presentation of the app at conferences, high-school outreach programs, or other public events. The iOS app was downloaded 8790 times. The temporal trend of the downloads follows the same pattern as the Android version. In addition, there is a peak of downloads in August and September 2017. We can explain this peak of download with the detection of the GRB170817A done by the Fermi-GRB(Goldstein et al., 2017), 1.7 s after the gravitational wave detected by the LIGO and Virgo interferometers(Abbott et al., 2017). This event raised the attention of the public on high-energy

[16] https://www.php.net/
[17] https://slurm.schedmd.com
[18] https://developer.apple.com/xcode/
[19] https://developer.android.com/studio
[20] https://www.java.com/it/

astrophysics. If we consider Android and iOS, the app was downloaded 11990 times.

The feedback from users, both from professional astronomers and from ordinary citizens, such as high-school students and professors involved in participation in high-school outreach program (Zinzi et al., 2021) has been, in general, very positive.

Here follows an excerpt from the all-positive reviews on the app store:

- "Very nice to be able to see the sky in real-time as the satellite sees it."
- "Application with very interesting content and easy to use!!!"
- "Really well-made app!"
- "Hi, great app and congratulations...! Well done and very interesting".

The AGILE Team members gave very positive feedback on the app usage, considering it a valuable tool to monitor the transient AGILE gamma-ray sky and allowing them to perform analyses directly from their mobile devices. This has reduced the reaction time of the AGILE Team to science alerts, particularly for the follow-up of flaring gamma-ray sources.

6. Limitations

The usage of two development environments for iOS and Android can be a limitation because the two versions of the application must be maintained using two different programming languages and environments. However, we thought that by using low-level tools and programming languages, we would ensure better compatibility in the future. Indeed, Java is a largely used programming language, and Objective-C, even if it is mainly used to develop iOS or macOS applications in restricted contexts, is based on the C programming language, which is largely used by the community.

Over the years, we did not change the main core of the application; instead, we just maintained compatibility and added some features. The requested updates were insufficient to justify a complete app redevelopment with newer technologies.

It is almost impossible to know in advance what new technologies or devices will be available in the next few years; this is a risk that we have to consider and try to mitigate using as standard tools as possible. AGILE is currently in the post-operative phase (up to December 2025), and we plan to maintain the app at least until the end of this phase. There is the possibility that the application will be maintained for a longer period, but this depends on resource availability.

The backend infrastructure can be another possible source of failure for the application. We mitigated this risk by using a Private Hosting Provider for high availability. In addition, we can move to another provider if needed. Moreover, the AGILE team, which manages the AGILE server, implemented possible mitigation of the out-of-service risk. We have geographically distributed backup servers and can redirect the application to the desired server.

7. Conclusion

This manuscript presents the AGILEScience mobile application developed for the AGILE space mission. Different app versions can be downloaded for free for Android and iOS Operating Systems. Altogether, the iOS and Android versions have been downloaded more than 11990 times. The application presents to the public the AGILE satellite status in near real-time and the main scientific results obtained by analyzing the data acquired by the instrument on-board the AGILE satellite, grants to the AGILE Team members access to a password-protected section showing scientific results of the AGILE real-time analysis software and allows the AGILE Team to start new analysis using the latest data and visualize the results from their mobile device.

A unique feature of this app is its direct interaction with the AGILE remote data archive, enabling the general public to submit new analyses and visualize results directly from the app, a first in gamma-ray astrophysics.

The application comprises several sections that can be opened using the main menu at the bottom of the mobile screen. The application retrieves public content from a WordPress website and can query this website for the desired information (e.g., news and images). News related to the scientific results obtained by the AGILE RTA system is retrieved with a connection to the AGILE servers, where the analyses are executed and the results are stored. Thanks to its private section, accessible only for the AGILE Team, this application is an important tool for AGILE researchers, and it can be used during daily work to visualize scientific results through mobile devices. Overall, the application improves the response time for the follow-up of transient events. In the future post-operations phase, without new real-time data acquisition, the AGILEScience app will be used as a reference for old and new results obtained with the consolidated AGILE data archive. In addition, this app could be considered a legacy model for the next generation of gamma-ray space missions.

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ASI/SSDC in Rome: the success of AGILE scientific operations depends on the effectiveness of the data flow from Kenya to SSDC and the data analysis and software management.

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