# The AGILE real-time analysis pipelines in the multi-messenger era

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## ABSTRACT

In the multi-messenger era, space and ground-based observatories usually develop real-time analysis (RTA) pipelines to rapidly detect transient events and promptly share information with the scientific community to enable follow-up observations. These pipelines can also react to science alerts shared by other observatories through networks such as the Gamma-Ray Coordinates Network (GCN) and the Astronomer's Telegram (ATels). AGILE is a space mission launched in 2007 to study X-ray and gamma-ray phenomena. This contribution presents the technologies used to develop two types of AGILE pipelines using the RTApipe framework and an overview of the main scientific results. The first type performs automated analyses on new AGILE data to detect transient events and automatically sends AGILE Notices to the GCN network. Since May 2019, this pipeline sent more than 40 Notices with a few minutes delay since data arrival. The second type of pipeline reacts to multi-messenger external alerts (neutrinos, gravitational waves, GRBs, and other transients) received through the GCN network and performs hundreds of analyses searching for counterparts in all AGILE instruments' data. The AGILE Team uses these pipelines to perform fast follow-up of science alerts reported by other facilities which resulted in the publishing of several ATels and GCN Circulars.

## 1. AGILE Space Mission

AGILE (Astrorivelatore Gamma ad Immagini LEggero - Light Imager for Gamma-Ray Astrophysics) is a scientific mission of the Italian Space Agency (ASI) launched on 23rd Apr 2007. The AGILE payload consists of the Silicon Tracker (ST), the SuperAGILE X-ray detector, the CsI(TI) Mini-Calorimeter (MCAL), and an AntiCoincidence System (ACS). The combination of ST, MCAL, and ACS form the Gamma-Ray Imaging Detector (GRID).
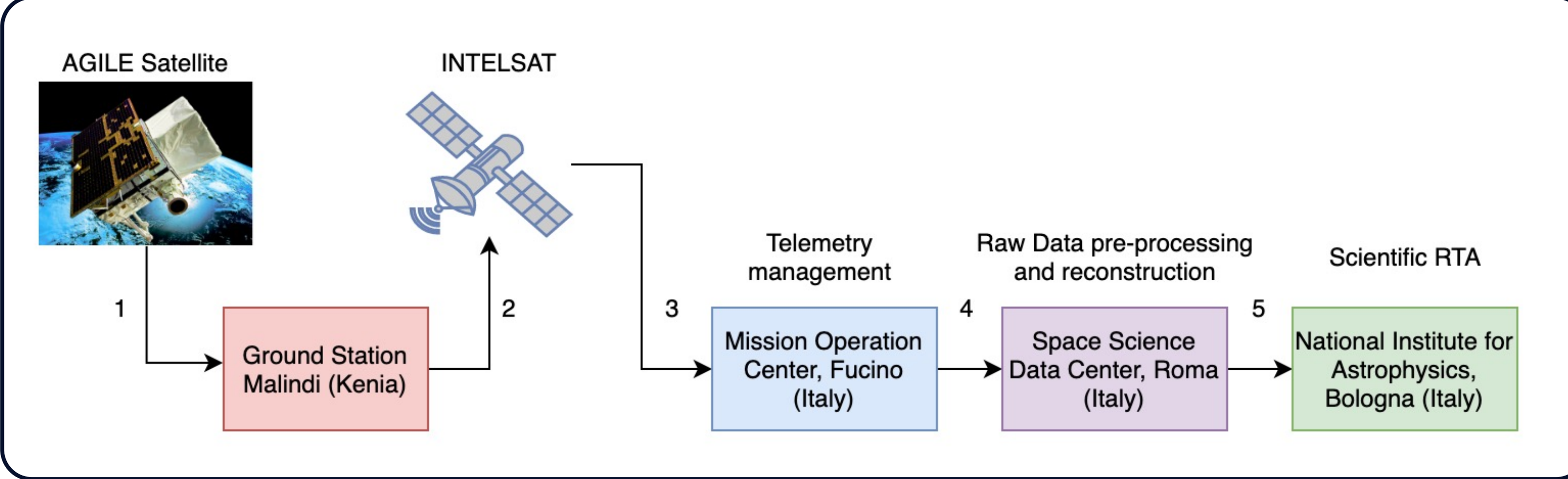


Fig. 1: AGILE data flow from the satellite to the scientific software

The data produced by the AGILE instruments are downlinked in the ASI ground station (Malindi, Kenya) (Fig. 1) almost at each orbit (about every 90 minutes) whenever the connection is available. The data are reconstructed at ASI Space Science Data Center, Roma (Italy) and sent to the data center at the National Institute for Astrophysics (INAF/OAS) in Bologna (Italy) for further analysis [1], performed by the automated software described in this contribution.

## 2. Multi Messenger context

In the multi-messenger context, the observatories share their information with the community through communication networks such as the Gamma-Ray Coordinates Network (GCN) to study the same physical phenomena with different "messenger" signals. Usually, the observatories develop pipelines to identify possible transient phenomena (e.g. GRBs), send science alerts to the astrophysical community, and speed up the reaction time to science alerts sent by other facilities.

## 3. AGILE RTA pipelines

The AGILE Team developed several RTA pipelines (Fig. 2) using the RTApipe framework [2]. There are two pipelines categories:

1. **Archive Pipeline** analyses the data collected into the Local Data Archive as soon as they are received.
2. **Science Alert Pipeline** reacts to science alerts received by the GCN network and starts a follow-up searching.

The results of both pipelines are saved on MySQL and in the File System. The AGILE Team can use a password-protected web Graphical User Interface to visualise the results obtained by the pipeline remotely and with low latency (seconds or minutes since the data arrival).
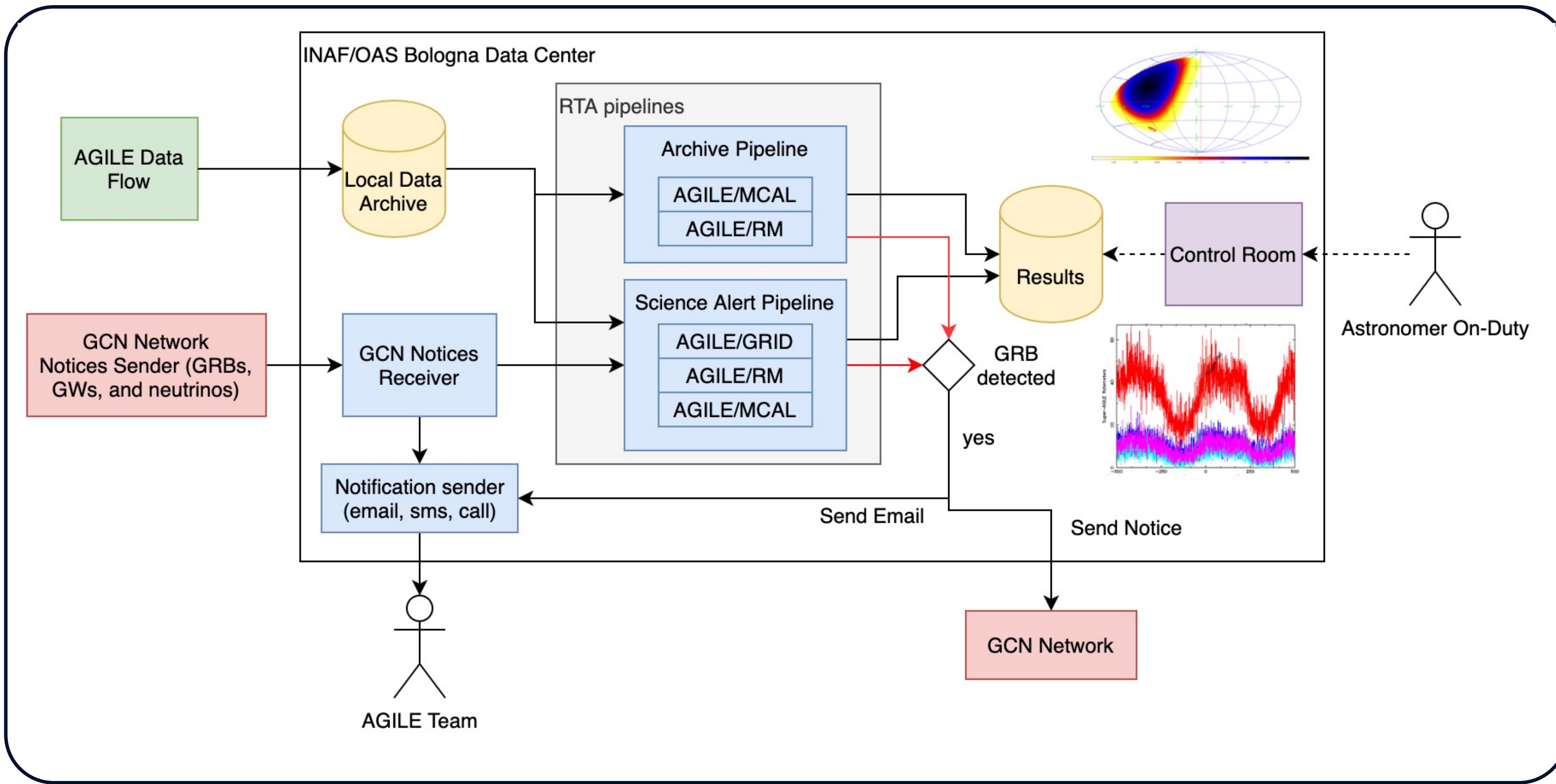


Fig. 2: Architecture of the AGILE RTA pipelines

## 3. Scientific Results

Since May 2019, the AGILE pipelines sent more than 40 automatic Notices to the GCN about GRBs. The AGILE Team sent more than 150 Circulars to the GCN network about the results obtained with the RTA pipelines during the follow-up of transient events detected by AGILE or by other observatories and several ATels communications and published several papers.

[1] A. Bulgarelli, *The AGILE Gamma-Ray observatory: software and pipelines*, Experimental Astronomy 48 (2019) 199.
[2] N. Parmiggiani, et al., *RTApipe, a framework to develop astronomical pipelines for the real-time analysis of scientific data*, ADASS XXX, Astronomical Society of the Pacific Conference Series, 2020