Forum della Ricerca Sperimentale e Tecnologica in INAF

June 22, 2022

Science Data Segment @ OAS

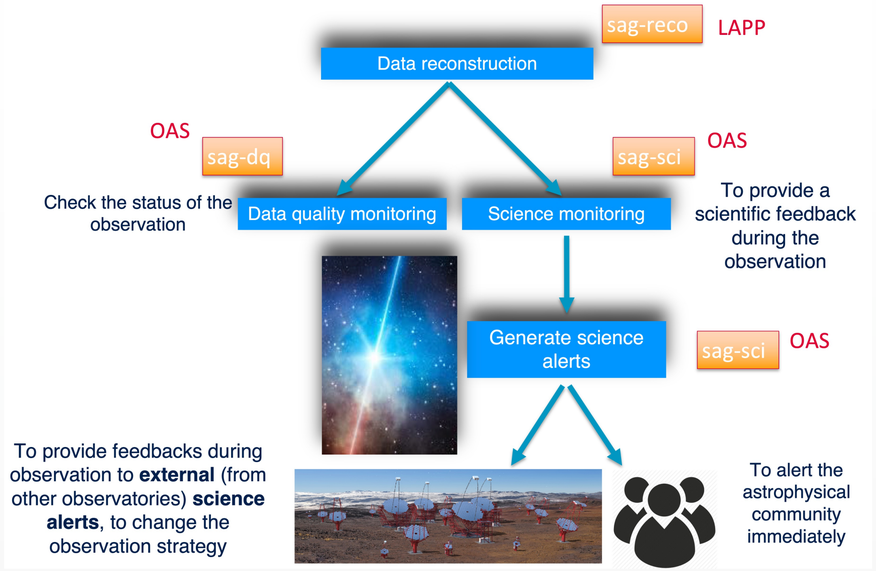
Andrea Bulgarelli

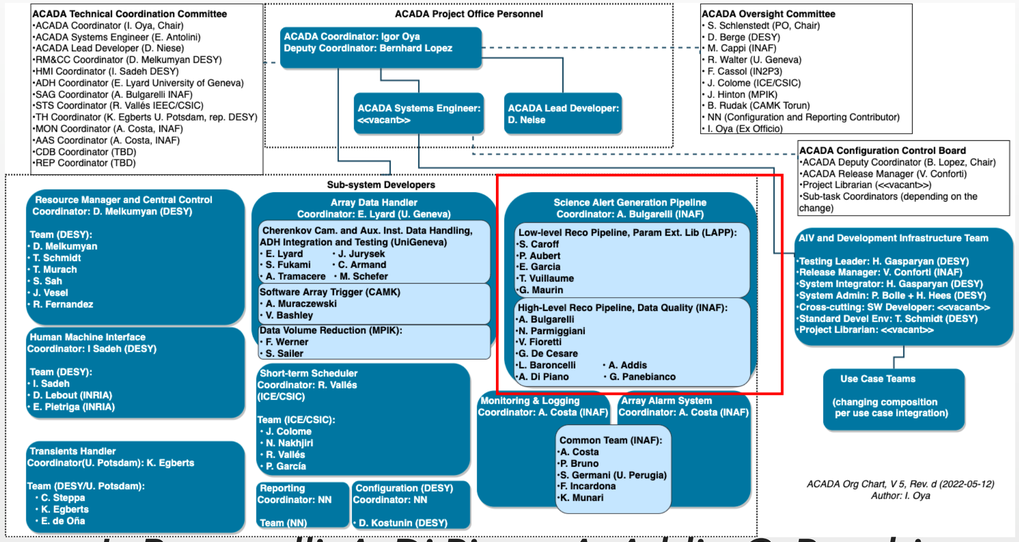
OUTLINE

- Andrea Bulgarelli: CTA and LST Science Alert Generation System
- Pino Malaguti: ARIEL INSTRUMENT OPERATION AND SCIENCE DATA CENTER
- Paola Battaglia: EUCLID NISP INSTRUMENT OPERATION
- Nicolò Parmiggiani: ASTRI Mini-Array
- Andrea Bulgarelli: Contributions to AGILE ground segment
- Gabriele Panebianco: Contributions to COSI ground segment

CTA OBSERVATORY SCIENCE ALERT GENERATION SYSTEM

- A **CTA Observatory/Array Control and Data Acquisition (ACADA)** work-package: **on-site** with the telescopes.
- On-line scientific analyses, **during the observation**.
- Input data rate: 5 GB/s
- The SAG must be capable of **issuing candidate science alerts with a latency of 20s** since data becomes available to ACADA.
- The SAG must **search for gamma-ray transient** phenomena on different timescales **from 10 seconds to 180 minutes**.
- The **sensitivity** of the analysis is required not to be worse than the one of the final analysis by more than a factor of 2.
- The ACADA/SAG is a key system in the context of **multi-messenger** and **multi-wavelength** astronomy.
- **AGILE heritage.**



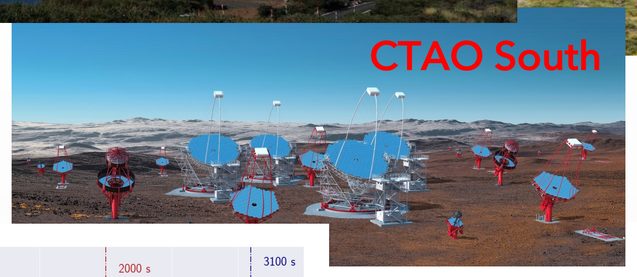


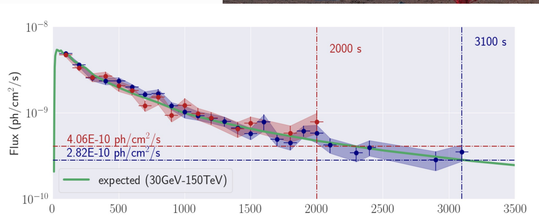
People involved: A. Bulgarelli (responsible), N. Parmiggiani, V. Fioretti, G. De Cesare, L. Baroncelli, A. Di Piano, A. Addis, G. Panebianco

CTA OBSERVATORY SCIENCE ALERT GENERATION SYSTEM/2

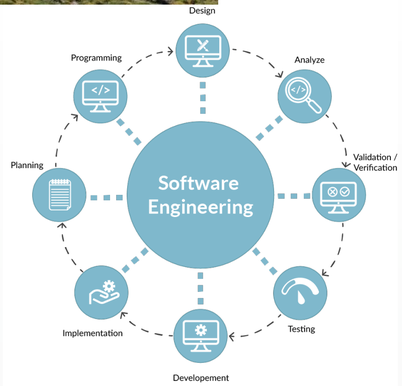
- People and tasks. All people are also developers.
  - **A. Bulgarelli** (permanent position): coordinator, algorithms definition
  - **N. Parmiggiani** (AdR): sag-sci responsible, SAG responsible for verification, ACADA database selection group leader, RTApipe framework
  - **L. Baroncelli** (PhD student on Data Science and Computation @ UNIBO): SAG supervisor responsible, software integration leader, sag-dq responsible, LST member and shifter, <u>on-line machine learning</u>
  - **A. Di Piano** (PhD student on machine learning @UNIMORE), LST member and shifter, SAG algorithms, SAG responsible for GRB and GW strategies, <u>on-line machine learning</u>
  - **G. Panebianco** (PhD student on Astrophysics @DIFA): simulation of light curves, atmospheric variability studies for CTA, gammapy, <u>algorithms and observing strategies definition</u>
  - **A. Addis** (AdR) sag-dq responsible for LST1
  - **G. De Cesare** (permanent position): sag-sci test leader
  - **V. Fioretti** (permanent position): short-term sensitivity, IRFs, CTA data challenge

SAG pipelines for CTAO and LST1.

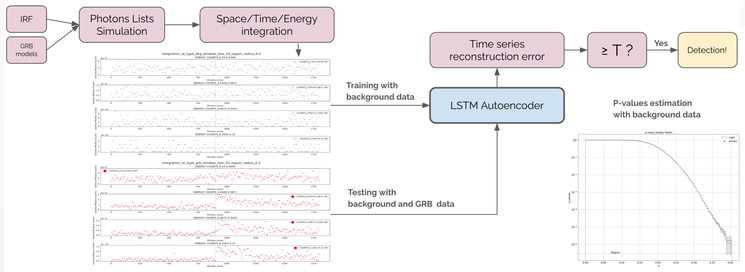




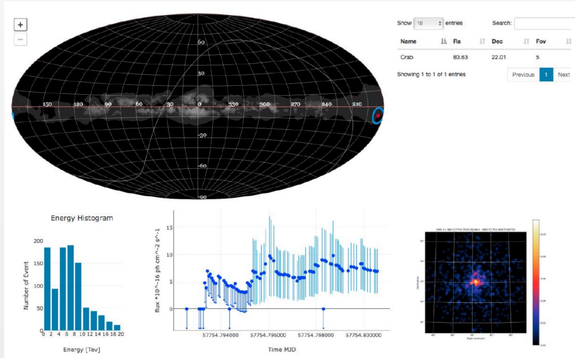
Science tools development, algorithms definition and statistical analysis for short timescale regime.



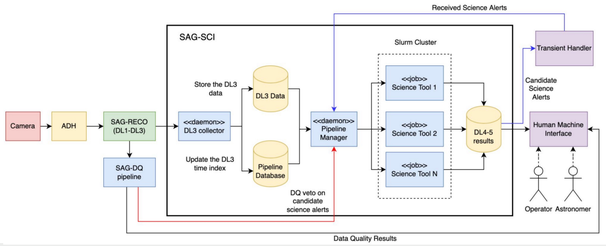
Software engineering and software project management activities.

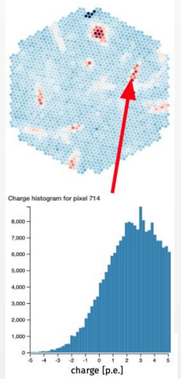


On-line machine learning algorithms for gamma-ray transient detection and classification.



Automated analysis pipeline development.





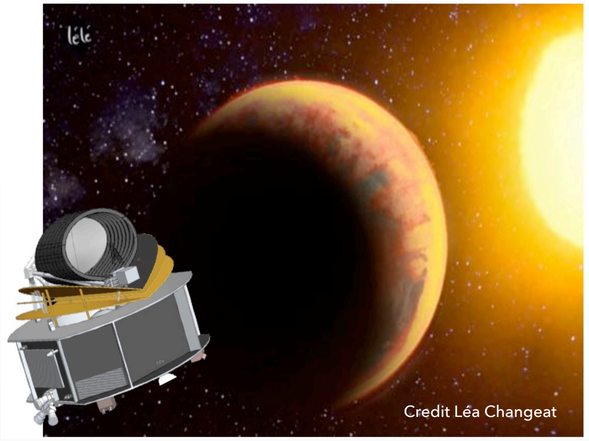
On-line data quality algorithms.

*People involved: **A. Bulgarelli (responsible), N. Parmiggiani, V. Fioretti, G. De Cesare, L. Baroncelli, A. Di Piano, A. Addis, G. Panebianco***

ARIEL
Atmospheric Remote-sensing Infrared Exoplanet Large-survey

ARIEL INSTRUMENT OPERATION AND SCIENCE DATA CENTER

- M4 mission in the ESA Cosmic Vision long-term plan
- Mission adopted on 12 Nov 2020
- Planned launch in 2029
- Nominal mission lifetime 4 years, possible extension to 6 years
- Key science questions to be addressed: What are the physical processes shaping planetary atmospheres? What are exoplanets made of? How do planets and planetary systems form and evolve?
- Launch by Ariane 6.2 from Kourou towards large amplitude orbit around L2
- Mission Operations Centre (MOC) at ESOC, Science Operations Centre (SOC) at ESAC, Instrument Operations and Science Data Centre (IOSDC) distributed across Ariel Consortium member States



- INAF-OAS involvement
  - Ariel Mission Co-PI
  - Overall responsibility of IOSDC (IOSDC Project Manager) and technical contributions to IOSDC (PA/QA, systems engineering)
  - Payload Thermal Systems Lead
  - Telescope AIV Manager
  - Contribution to Telescope Optics
  - Instrument Control Unit PA/QA

People involved: ***G. Malaguti (Co-PI), N. Auricchio, F. Cortecchia, E. Diolaiti, M. Lombini, G. Morgante, F. Schiavone, L. Schreiber, L. Terenzi***

ARIEL INSTRUMENT OPERATION AND SCIENCE DATA CENTER/2

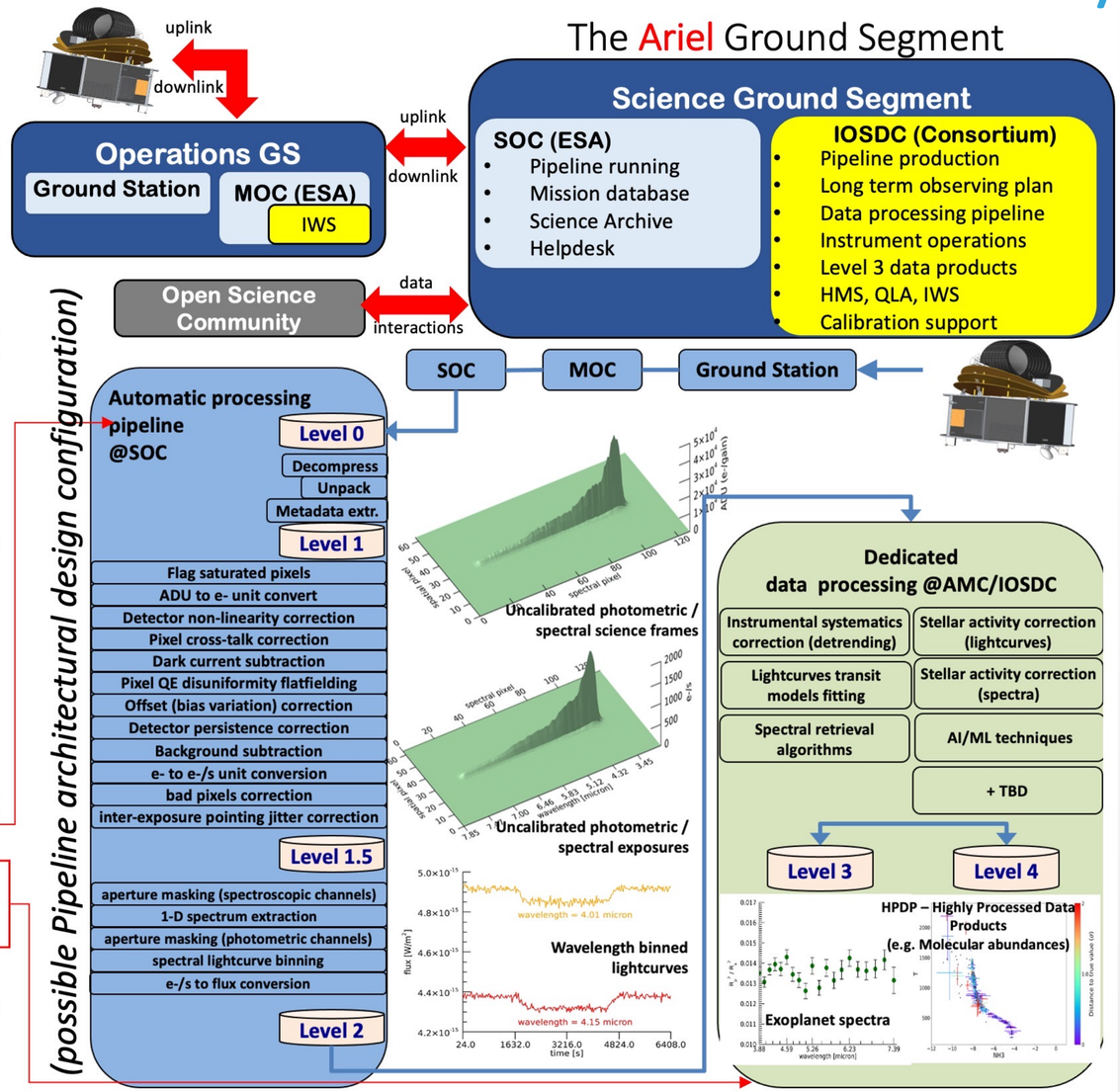
Ariel (Atmospheric Remote-sensing Infrared Exoplanet Large-survey), ESA Cosmic Vision M4 mission, will study composition, formation and evolution of exoplanets and their atmospheres, by surveying a diverse sample of ~1000 exoplanets, simultaneously in visible and infrared.

INAF roles in **Ariel** include: two CoPIs, Systems Teams and Science WG members, and the co-responsibility (jointly with RAL UK) of the **Instrument Operations and Science Data Centre** (**IOSDC**) within the Mission **Ground Segment** (GS).

Ariel GS is formed by the Operations Ground Segment (Ground Stations + MOC) and the **SGS - Science Ground Segment**. SGS is composed of the Science Operation Centre (SOC, c/o ESA), and **IOSDC**, under Consortium responsibility.

IOSDC key tasks and responsibilities include:

- **Data processing Pipeline** (running @SOC) for the production of **L1** (photometric/spectral images) and **L2** (target lightcurves),
- **L3** (exoplanets spectra) and **>L3** (Highly Processed Data Products, e.g. molecular abundances),
- **Long Term Observation Planning Tools**,
- **Health Monitoring Systems**, **Instrument WorkStation** and **Quick Look Analysis** tools,
- **Operations** and **Calibration** support.



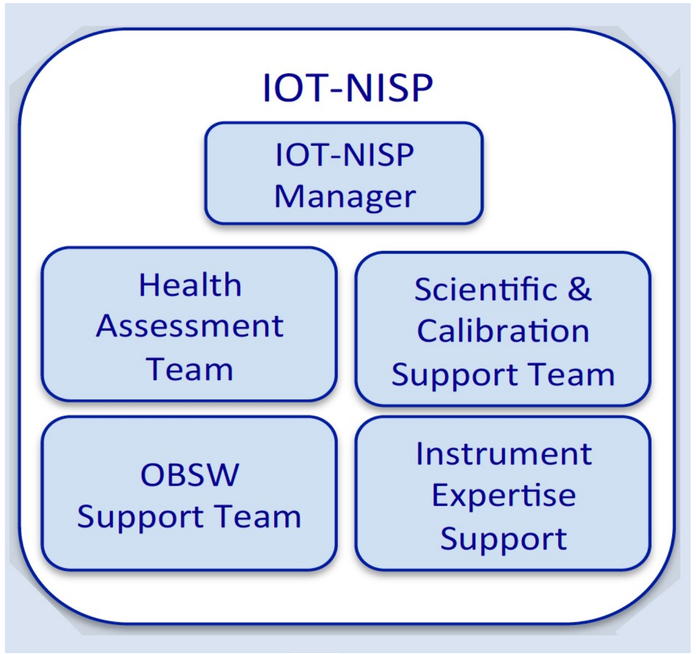
(ASI support via Accordo N. 2021-5-HH.0 «Partecipazione italiana alla fase B2/C della missione Ariel» is acknowledged)

People involved: G. Malaguti (Co-PI), N. Auricchio, F. Cortecchia, E. Diolaiti, M. Lombini, G. Morgante, F. Schiavone, L. Schreiber, L. Terenzi

EUCLID NISP INSTRUMENT OPERATION

- NISP (Near Infrared Spectrometer and Photometer) is a spectro-photometer (detecotors cooled down to 100K).
- It is located in the focal plane of the ESA-Euclid telescope, together with a visual imager (VIS).
- Euclid scientific goal: to measure the expansion history of the Universe and the growth rate of cosmic structures (dark matter, dark energy).

The **Instrument Operation Team** (IOT) is an Euclid Consortium group that belongs to the Science Ground Segment (SGS).



- Paola Battaglia NISP IOT Manager
- Natalia Auricchio NISP IOT member
- Ruben Farinelli NISP IOT member
- Enrico Franceschi NISP IOT member
- Fulvio Gianotti NISP IOT member
- Eduardo Medinaceli NISP IOT member
- Massimo Trifoglio NISP IOT member

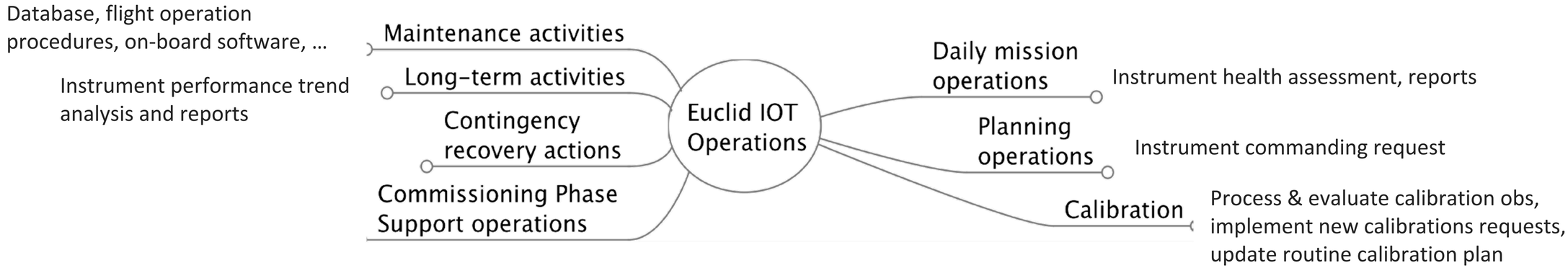
- The IOT is the connection point between SGS and Science Operation Center (led by ESA).
- **IOT NISP**:

1. is in charge of instrument maintenance and monitoring
2. will support SGS in the development of instrument operational modes

People involved: ***P. Battaglia (NISP IOT Manager), N. Auricchio, R. Farinelli, E. Franceschi, F. Gianotti, E. Medinaceli, M. Trifoglio***

EUCLID NISP INSTRUMENT OPERATION/2

IOT NISP activities are shown in picture below:



- IOT NISP has been early involved in instrument testing (in charge to Instrument Developing Team)
- It is depositary of **instrument knowledge** (support to data analysis for **instrument systematic effects)**
- Until launch: support to the **preparation of the System Validation Test (**validate the mission control system and procedures, evaluate the capabilities of the ground segment to operate the space segment).

NISP IOT Manager among Ground Segment people at the last System Validation Test

People involved: ***P. Battaglia (NISP IOT Manager), N. Auricchio, R. Farinelli, E. Franceschi, F. Gianotti, E. Medinaceli, M. Trifoglio***

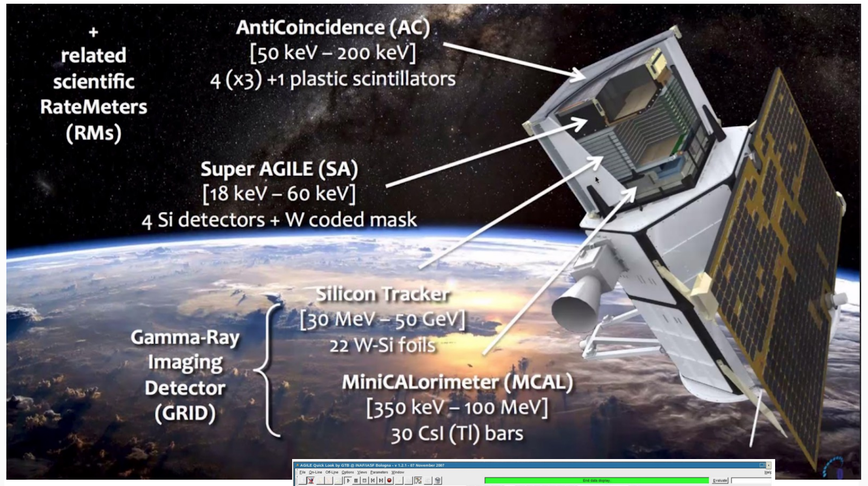
ASTRI MINI-ARRAY: OBSERVATION QUALITY SYSTEM AND AUTOMATED SCIENCE PRODUCT GENERATION

- The **On-Line Observation Quality System** is part of the ASTRI Mini-Array **on-site** SCADA software:
  - **execute data quality checks on the data acquired in real-time** by the Cherenkov camera and intensity interferometry instruments deployed in the nine ASTRI Mini-Array telescopes.
  - **high data rate** generated by the instruments (up to 4.5 GB/s for the intensity interferometry observations) and the Cherenkov event rate of 1000 Hz.
- The **Automated Science Product Generation Pipeline** of the ASTRI Mini-Array will be deployed in the **off-site data centre** in Rome **to execute automated scientific analysis**. It is part of the Data Processing System that manages the automated analyses starting from the raw data received from the Array Data Acquisition system on-site, to execute
  - **short-term analysis**: executed automatically as soon as the event list is received (~ 20 min since data acquisition)
  - **long-term analysis**: executed without time constraints and based on the best available calibration factors.

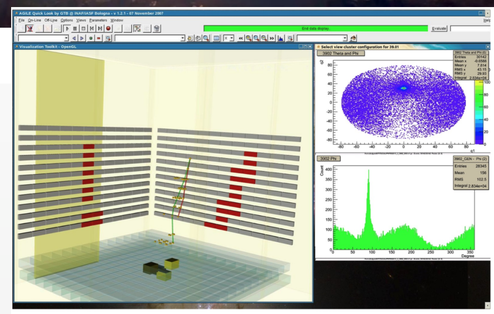
People involved: ***N. Parmiggiani (responsible), L. Baroncelli***

AGILE: CONTRIBUTIONS TO GROUND SEGMENT

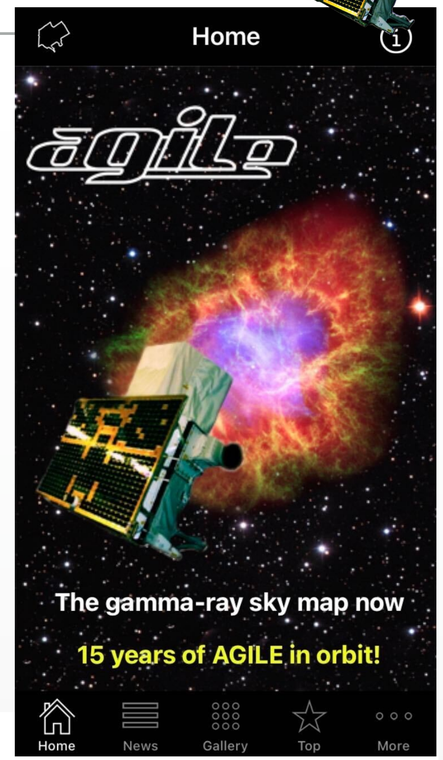
- Launch: April 23, 2007. AGILE is fully operational, nominal status, and active in
  - gamma-ray astrophysics
  - terrestrial atmosphere & magnetosphere physics
  - search of GRB, GW counterparts, neutrinos, Fast Radio Bursts and other transients
- **Contributions to ASI/SSDC Science Ground Segment:**
  - AIV software
  - AGILE P/L Health Monitoring System
  - Telemetry Preprocessing System (from telemetry to FITS file)
  - P/L Monte Carlo simulations
  - New AGILE/GRID reconstruction techniques
  - AGILE Science Tools with INAF/IASF Milano
  - AGILEScience App
  - Agilepy
  - AGILE Real-Time Analysis



The AGILE Payload



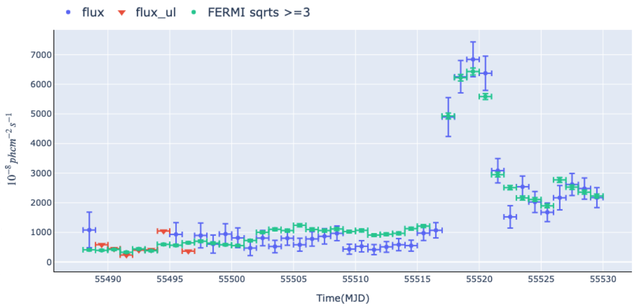
The AIV software



AGILEScience App, to analyse science data using mobile phone

AGILE P/L Health Monitoring System

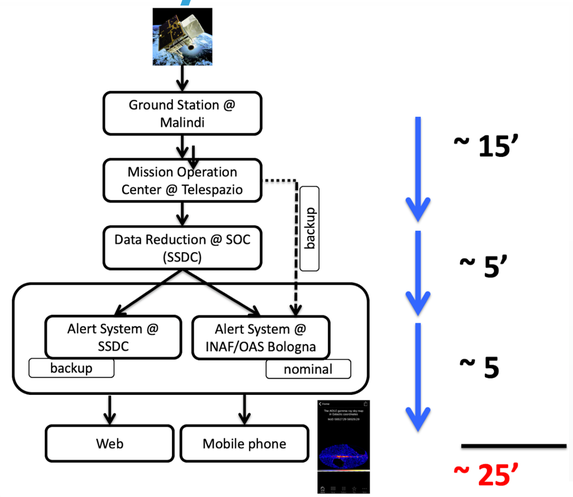
Agilepy is an open-source Python package developed at INAF/OAS Bologna to analyse AGILE/GRID data built on top of the command-line version of the AGILE/GRID Science Tools.



People involved: ***A. Bulgarelli (responsible), M. Trifoglio, F. Gianotti, N. Parmiggiani, A. Addis, L. Baroncelli, V. Fioretti, A. De Rosa***

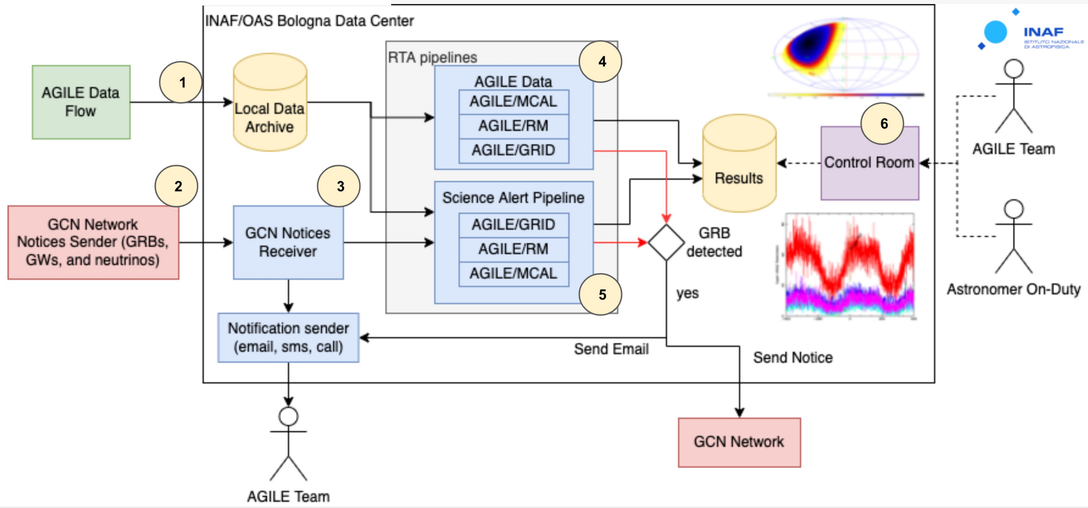
AGILE: CONTRIBUTIONS TO GROUND SEGMENT/2

- **AGILE Real-Time Analysis** @ OAS, backup chain @ ASI/SSDC: first scientific results are within 25 minutes from data downlink.
- Since the beginning, the **monitoring of the gamma-ray sky** with a rapid and efficient alert system led the publication of
  - 204 Astronomer Telegram and 247 GCNs circulars.
  - AGILE follow-up of all GW events resulted in 96 GW-AGILE type GCNs.
  - From May 2019 automatic GCN notices on MCAL: more than 70 automated notices have been sent to the GCN network about GRBs without human intervention.
- Many lessons learned after 15 years of operation on team experience, mission configuration, software optimization and management.



AGILE ground segment and real-time analysis, distributed between ASI/SSDC and INAF/OAS Bologna

AGILE real-time analysis @ OAS. Backup chain @ ASI/SSDC

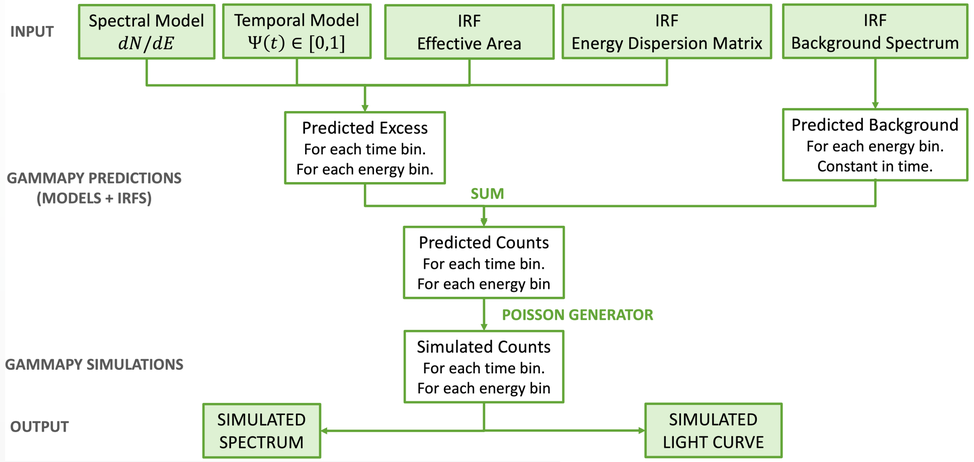


1. The system at INAF/OAS Bologna receives the LV2 data from SSDC.
2. Alerts are received from the GCN network.
3. **GW**: one **wakeup systems** alerts the AGILE Team if a new alert from LIGO/Virgo collaboration is received.
4. **PIPELINES ON AGILE DATA**:
   a. AGILE/MCAL pipeline searches GRB and TGFs. In the presence of a GRB identified by MCAL pipeline, an automated GCN notice is submitted to the GCN network.
   b. AGILE/RM analyses SuperAGILE, MCAL, GRID and AC ratemeters, to search GRBs and solar flares
   c. AGILE/GRID (SPOT6) search flares at daily basis above 100 MeV
5. **PIPELINES ON EXTERNAL SCIENCE ALERTS**: If new alerts are received, the **science alert pipeline** performs the required scientific analysis of GRID, MCAL and ratemeter data
   a. The pipeline alerts the AGILE Team (SMS, email and call) preparing two templates for the GCN Circulars that the Astronomer on-duty can use to send an answer to the external science alert.
6. **Control Room**: to monitor both AGILE technical information (data archive, data flow etc.) and scientific results produced by the pipelines.

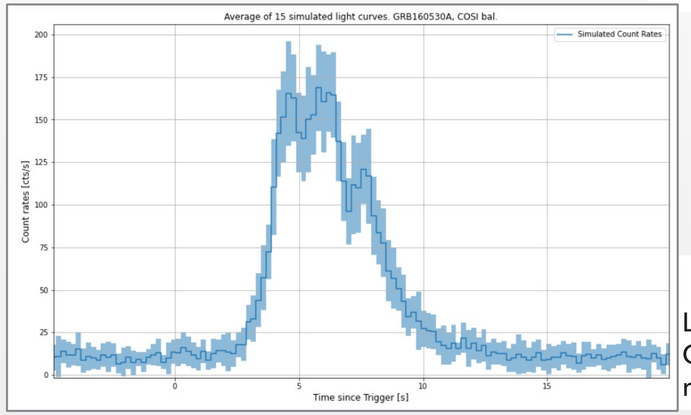
*People involved: **A. Bulgarelli (responsible), M. Trifoglio, F. Gianotti, N. Parmiggiani, A. Addis, L. Baroncelli, V. Fioretti, A. De Rosa***

COSI: CONTRIBUTIONS TO GROUND SEGMENT

- **COSI:** selected by NASA for the SMEX program. Launch: September 2025. The MeV band: a bridge between the thermal and non-thermal Universe.
- INAF/OAS involvement:
  - Data pipeline
  - P/L simulations
- **Development of a simulation tools for transients: light curve generator**
  - Create a random GRB light curve, and polarization distribution according to different models, starting from e.g. GBM catalogues, determine spectral and temporal model distributions for short and long GRBs.
  - Include other transients: SGRs, AGN, solar flares, and other relevant transients.
  - Sub-project: light curve generation using neural networks such as VAEs, GANs, LSTM / RNNs to create new random light curves with similar properties than the real ones.



Workflow for light curve generation



Light curve simulation of a GBM GRB using COSI instrument response functions

People involved: ***G. Panebianco, A. Bulgarelli, V. Fioretti, A. Di Piano, N. Parmiggiani***

Backup slides

ASTRI MINI-ARRAY: OBSERVATION QUALITY SYSTEM

- The OOQS is part of the SCADA software system deployed in the on-site data center that manages the startup, shutdown, configuration, and control of all site assemblies and sub-systems.
- The OOQS aims to execute data quality checks on the data acquired in real-time by the Cherenkov camera and intensity interferometry instruments deployed in the nine ASTRI Mini-Array telescopes.
- The OOQS is designed to manage the high data rate generated by the instruments (up to 4.5 GB/s for the intensity interferometry observations) and the Cherenkov event rate of 1000 Hz.
- We defined the Use Cases and the Software Requirements considering the experience and the know-how acquired in other projects (the ASTRI Horn prototype, and the AGILE space mission) and collaborating with domain experts.
- The OOQS is a critical system because it detects abnormal conditions and sends notifications to the Central Control System and the Alarm System for a fast reaction.
- In additions, the Operator visualizes the OOQS results through the Operator HMI during the supervision of the observations and takes corrective actions if needed.

People involved: ***N. Parmiggiani (responsible), L. Baroncelli***

ASTRI MINI-ARRAY: AUTOMATED SCIENCE PRODUCT GENERATION

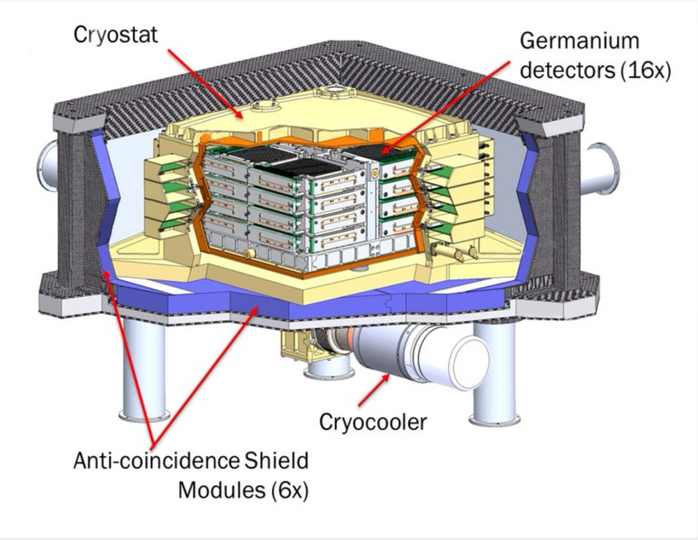
- The Automated Science Product Generation Pipeline of the ASTRI Mini-Array will be deployed in the off-site data center in Rome. It is part of the Data Processing System that manages the automated analyses starting from the raw data received from the Array Data Acquisition
- This pipeline executes scientific analysis starting from the event list (EVT3) and the IRF3 generated by the automated reconstruction pipeline.
- The pipeline must satisfy two main operating modes:
  - short-term analysis: executed automatically as soon as the event list is received (~ 20 min since data acquisition) and reduced at the data center (~10 min since data receiving) to generate scientific quick-look results that can be visualized using the web Scientific GUI by the Astronomer on-duty.
  - long-term analysis: executed without time constraints and based on the best available calibration factors. It generates more accurate scientific results that will be stored in the Science Archive and available to scientific users.

People involved: ***N. Parmiggiani (responsible), L. Baroncelli***

COSI: CONTRIBUTIONS TO GROUND SEGMENT

- The MeV band: a bridge between the thermal and non-thermal Universe
- Selected by NASA for the SMEX program
- Launch: September 2025
- Duration: 26 months
- INAF/OAS involvement
  - Data pipeline
  - P/L simulations

Parameter	Requirements
Energy range	0.5-2 MeV for emission lines 0.2-1 MeV for polarization 0.4-0.5 MeV ortho-positronium continuum 0.5-5 MeV for positron continuum (e^+ injection energy)
Field of view	25% sky (instantaneous) 100% sky (daily) for transient surveys and all-Galaxy coverage
Energy resolution	0.8% FWHM @ 1.157 MeV for ^{44}Ti emission lines
Angular resolution	2.0º FWHM @ 1.809 MeV for ^{26}Al imaging
Localizations	<1.0º for GRBs



People involved: ***G. Panebianco, A. Bulgarelli, V. Fioretti, A. Di Piano, N. Parmiggiani***