cherenkov telescope array

CTA @ OAS Bologna

OAS Days, Bologna December 17st, 2018

A. Bulgarelli, L. Amati, L. Baroncelli, M. Cappi, A. Comastri, G. De Cesare, V. Conforti, S. Ettori, A. De Rosa, M. Dadina, F. D'Ammando, V. Fioretti, F. Gianotti, R. Gilli, E. Maiorano, L. Nicastro, P. Grandi, E. Palazzi, N. Parmiggiani, F. Russo, V. Sguera, G. Stratta, S. Tampieri, E. Torresi, M. Trifoglio, G. Zollino

Outline

- Introduction to CTA = **Cherenkov Telescope Array**
  - » Why CTA?
  - » What is CTA?
  - » How does CTA work?

- Current activities
  - ASTRI and AIV
  - Computing Infrastructure
  - Science: see Eleonora Torresi's talk
  - Observatory Use Cases
  - Scientific pipelines
  - Data Challenges and Scientific Validation

People @ OAS

- People @ OAS
  - ASTRI and AIV + Computing Infrastructure: M. Trifoglio (spokesperson), F. Gianotti, V. Conforti, F. Russo, G. De Cesare, A. Tacchini, A. Bulgarelli, V. Fioretti
  - Science: see Eleonora Torresi's talk
  - Scientific pipelines + Observatory Use Cases + Data Challenges and Scientific Validation
    - Development:
      - A. Bulgarelli (resp), G. De Cesare, V. Fioretti (scientific consultant)
      - PhDs: N. Parmiggiani (Big Data, University of Modena), L. Baroncelli (Machine Learning, University of Bologna, PhD on Data Science)
      - master thesis: G. Zollino (Big Data), S. Tampieri (astronomer, data analysis).
    - Scientific validation: G. Stratta, F. D'Ammando, E. Torresi, E. Maiorano, G. De Cesare
    - Technical support: L. Nicastro (DBMS), A. De Rosa
  - PHYS: L. Amati, M. Cappi, A. Comastri, M. Dadina, S. Ettori, R. Gilli, P. Grandi, L. Nicastro, E. Palazzi, V. Sguera + people of "pipeline scientific validation"

Some photos…

V. Fioretti

G. Stratta

E. Torresi

L. Baroncelli

A. Bulgarelli

V. Conforti

G. De Cesare

F. Gianotti

N. Parmiggiani

A. Tacchini

M. Trifoglio

F. Russo

G. Zollino

cherenkov telescope array

The CTA Project

Why CTA?

- CTA will look in the energy domain ~20GeV - 300TeV.
- Some Fundamental Questions:
  - » Cosmic Particle Acceleration
    - How and where are particles accelerated?
    - How do they propagate?
    - What is their impact on the environment?
  - » Probing Extreme Environments
    - Which/how are processes close to neutron stars and black holes?
    - What physical processes are at work close to neutron stars and black holes?
    - What happens in the relativistic jets, winds and explosions?
  - » Physics Frontiers
    - What is the nature of dark matter?
    - How dark matter is it distributed?
  - » … and many others…

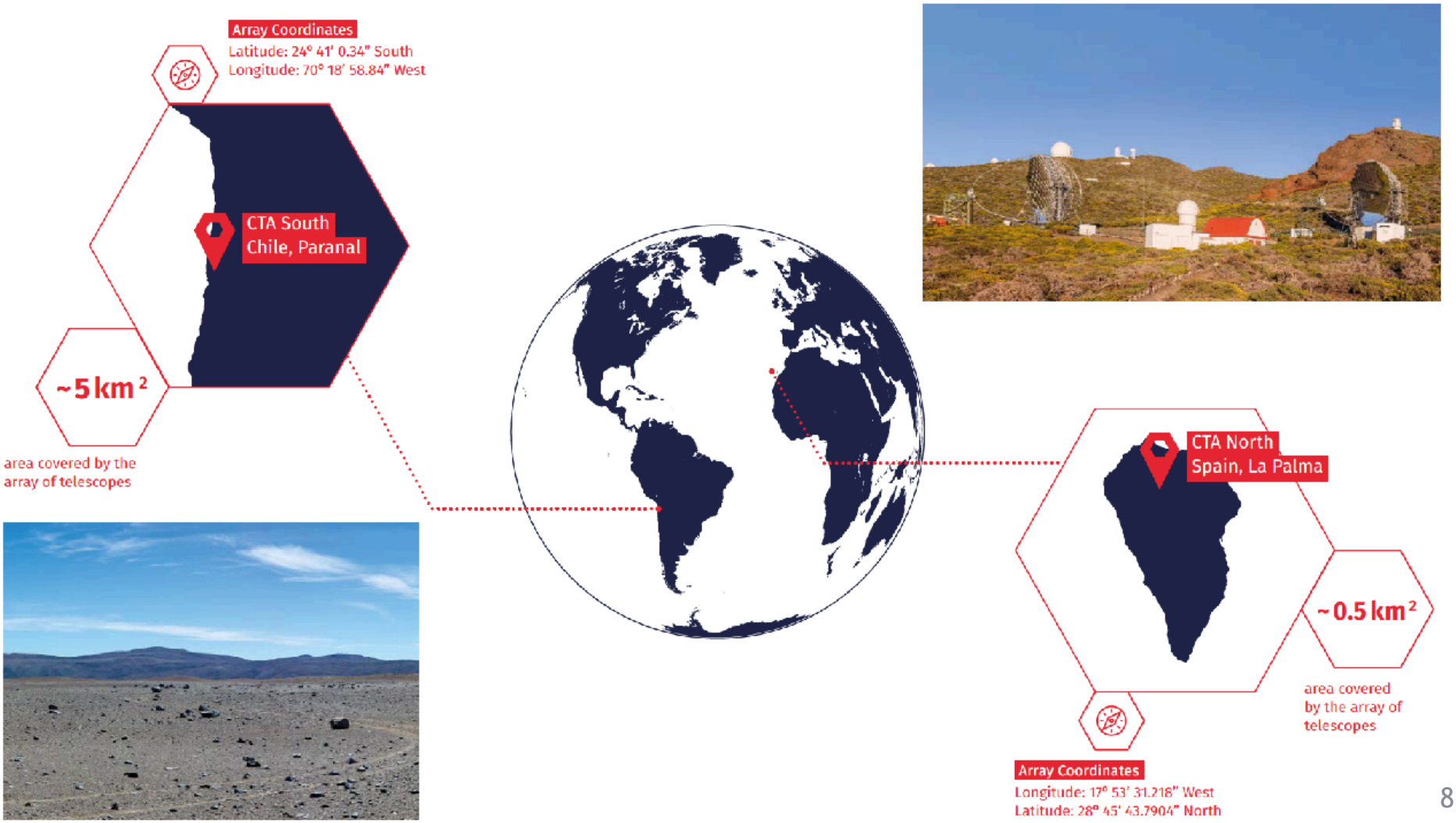
Ref.: Science with the Cherenkov Telescope Array - https://arxiv.org/abs/1709.07997

Why CTA?

- The key targets in the Universe are:

What is CTA?

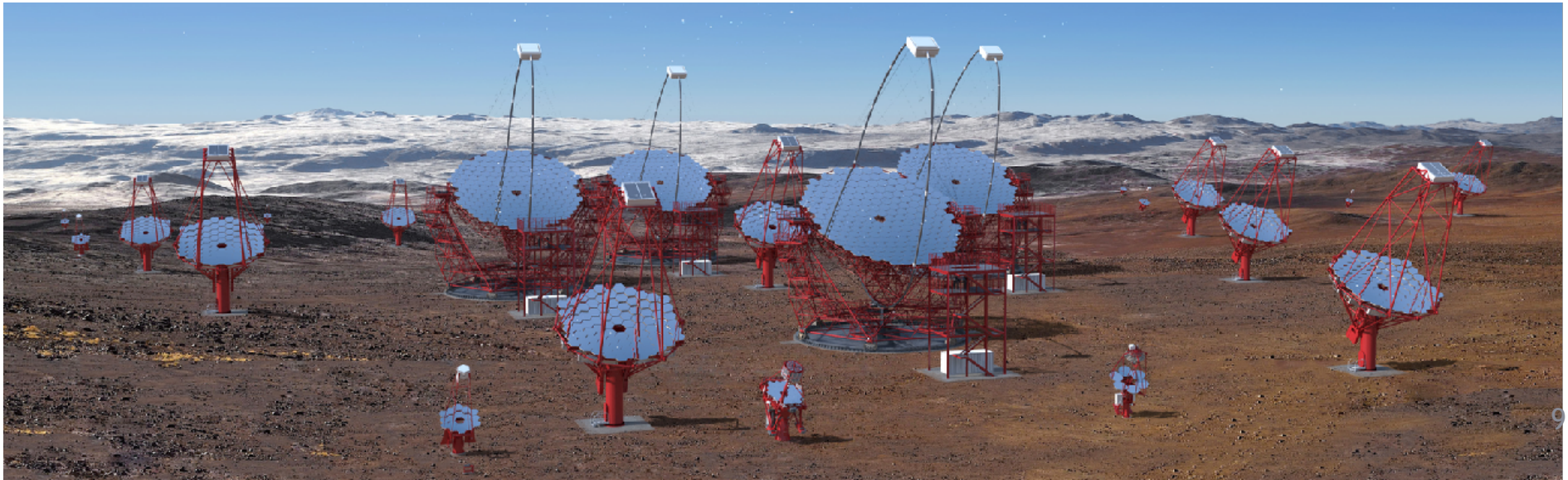
- Two “eyes” (arrays of Cherenkov Telescopes) on the sky



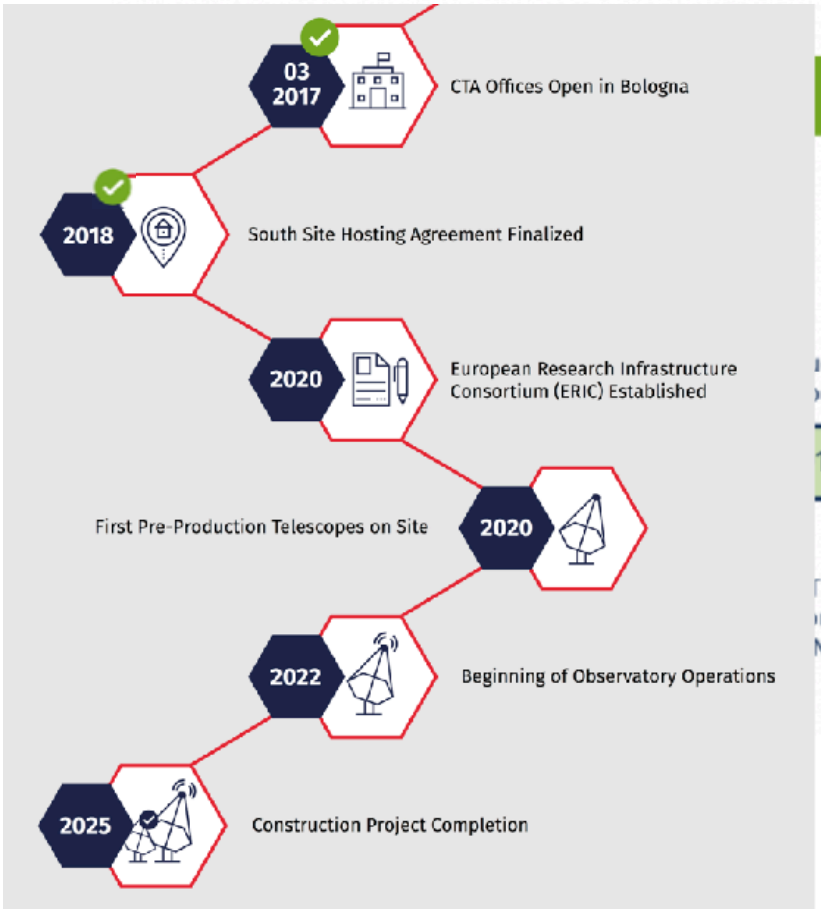
What is CTA?

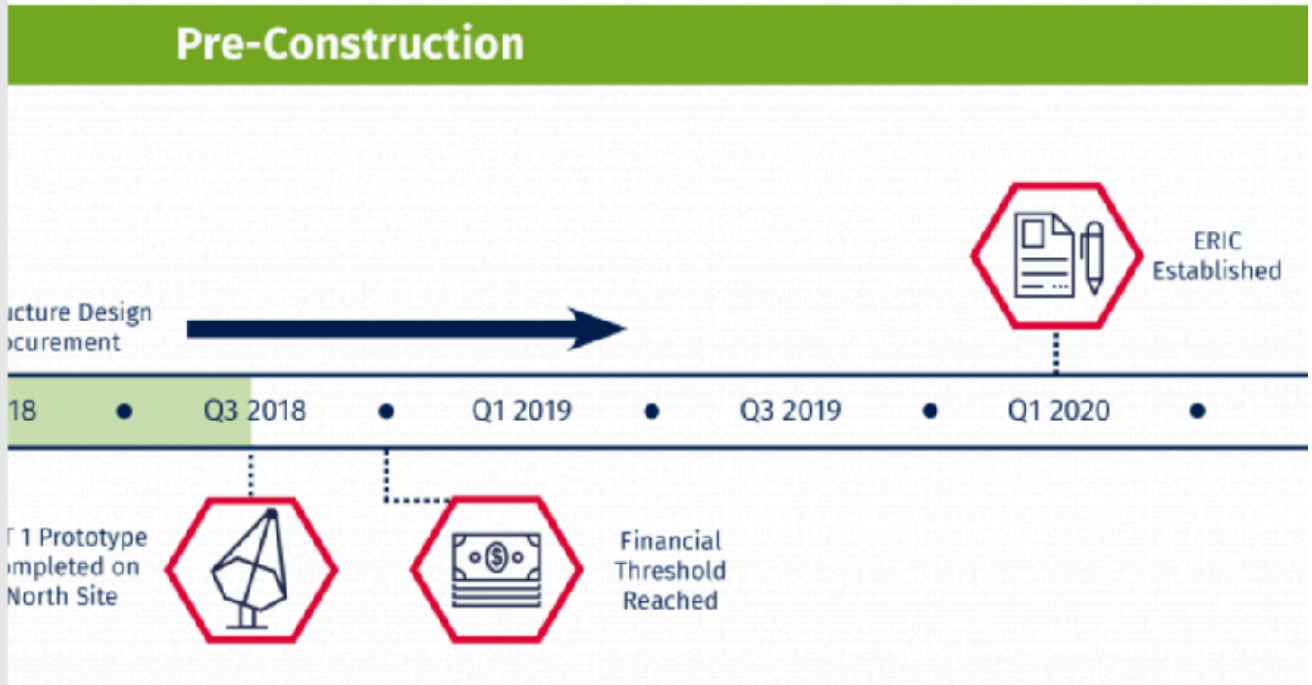
- North: 19 telescopes spread out over ~0.5 km^2 (4 LSTs, 15 MSTs)

- South: 99 telescopes spread out over ~5km^2 (4 LSTs, 25 MSTs, 70 SSTs)

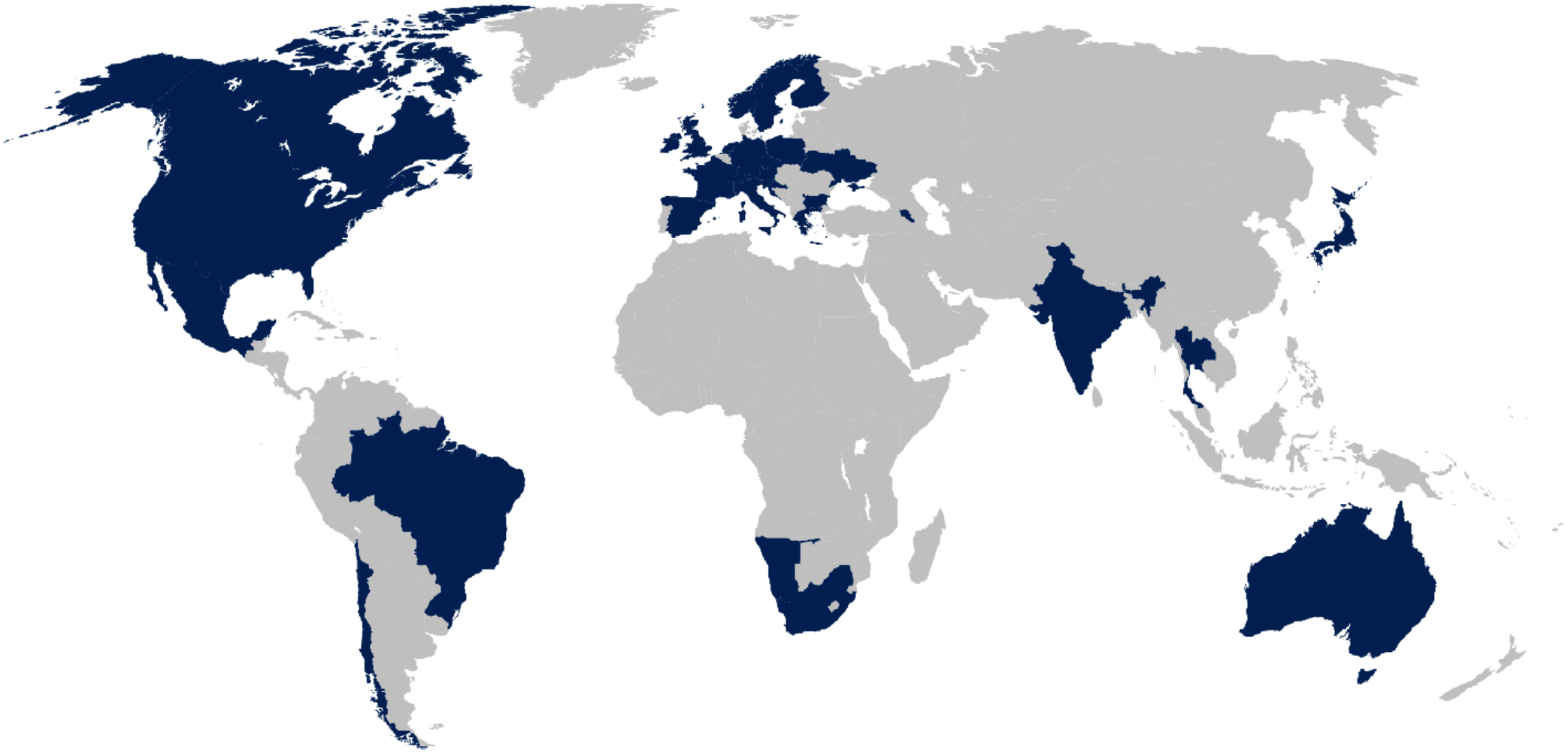


Project phases





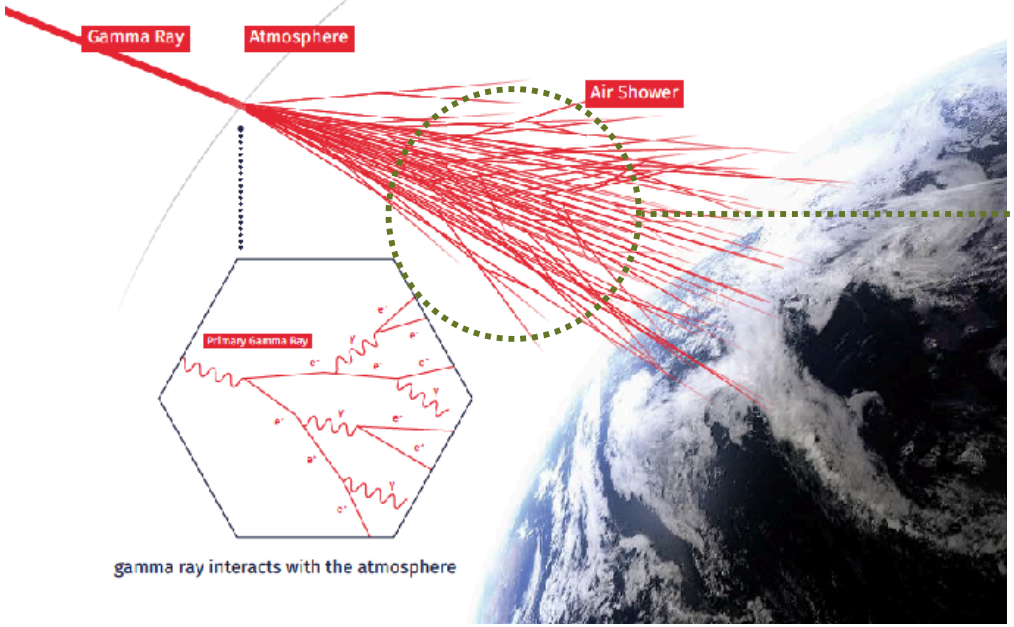
CTA Consortium

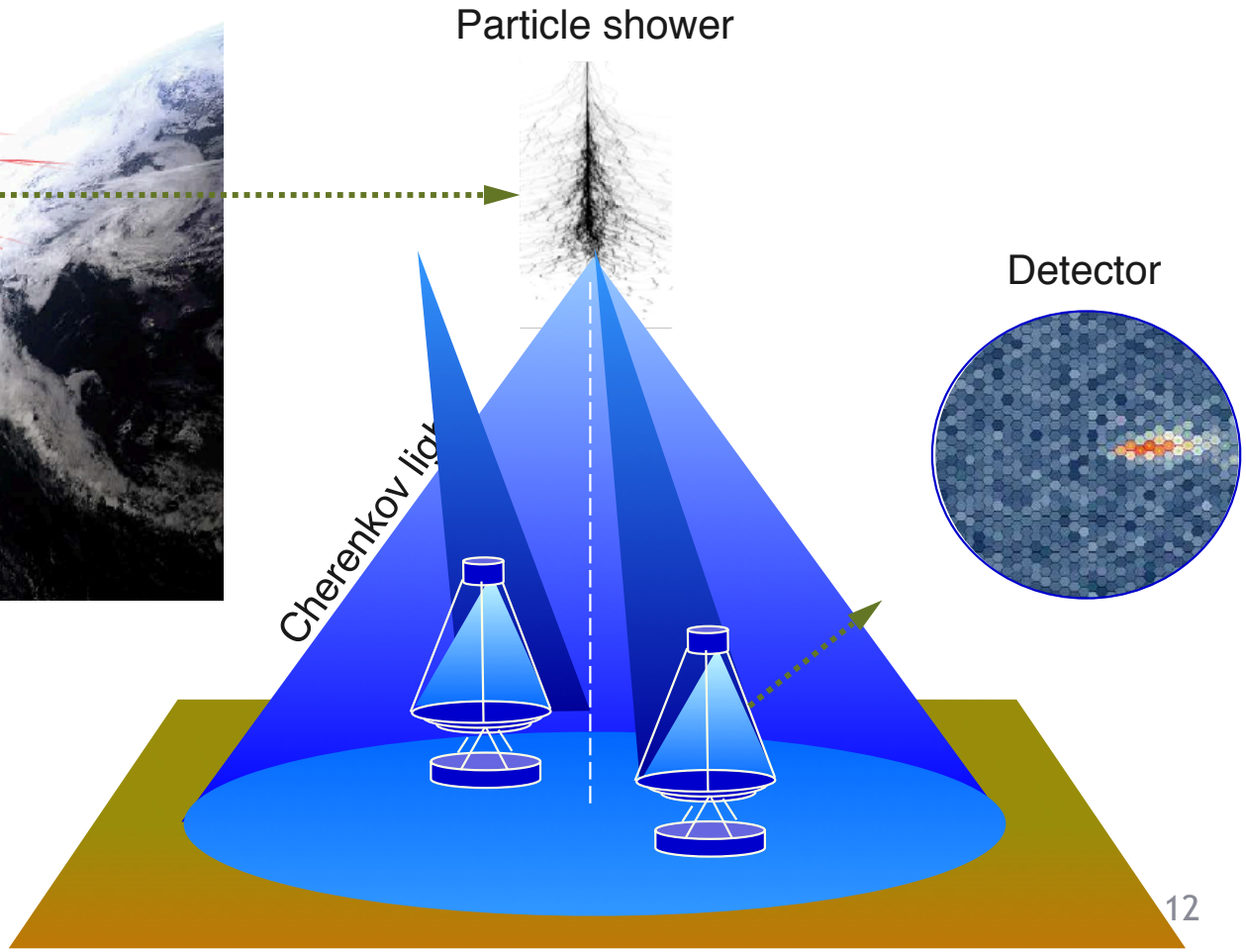


CTA is a global effort with more than 1,400 scientists and engineers from about 200 institutes in 31 countries involved in directing CTA's science goals and array design.

How does CTA work?

- Capture the Cherenkov light produced during the interaction between a gamma particle and the Earth atmosphere.





IACT = IMAGING AIR CHERENKOV TELESCOPES

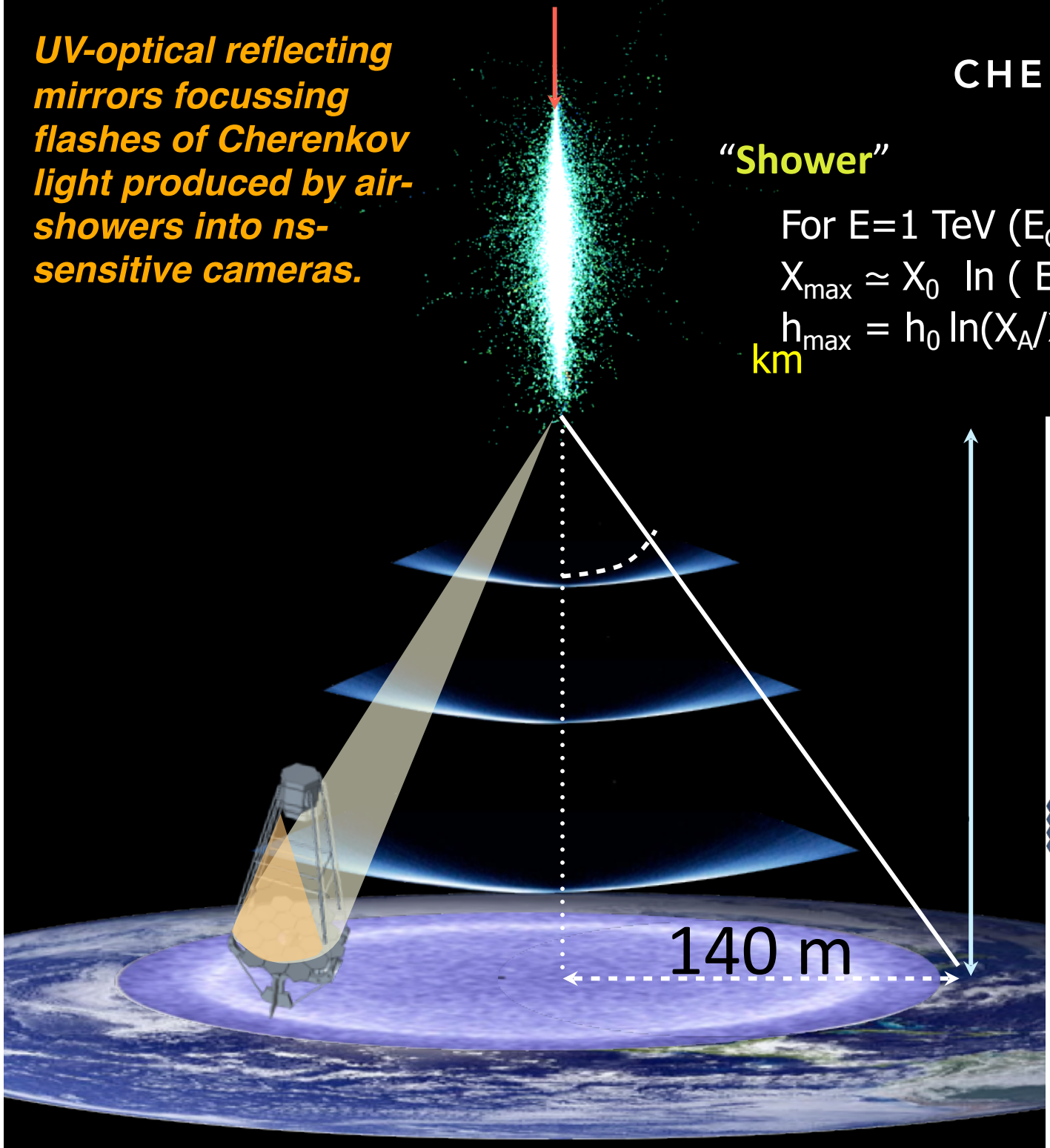
UV-optical reflecting mirrors focussing flashes of Cherenkov light produced by air-showers into ns-sensitive cameras.

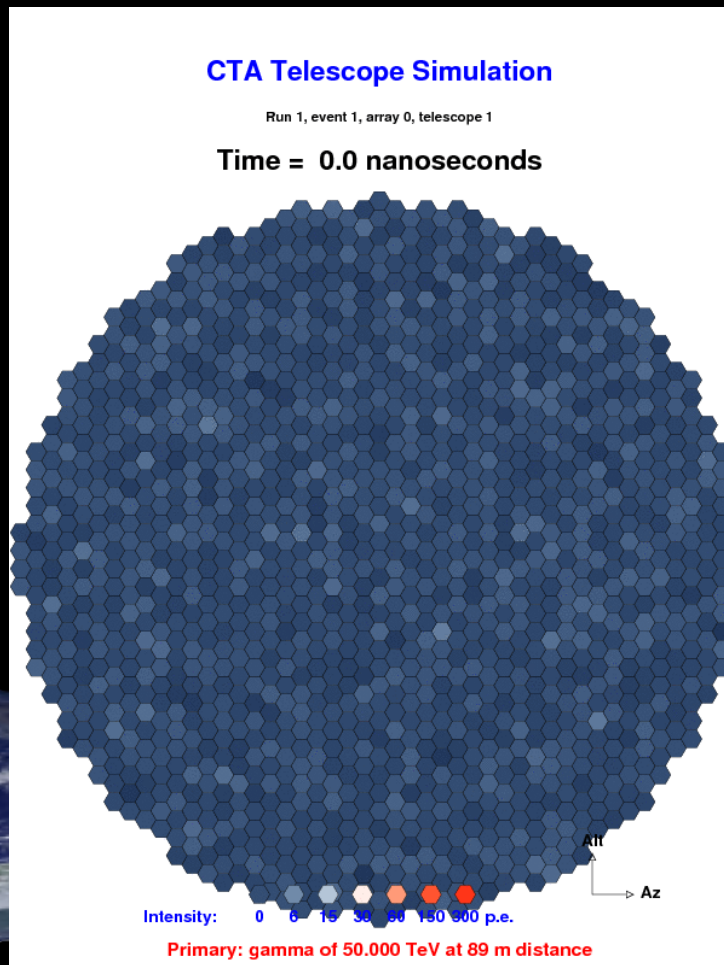
"Shower"

For E=1 TeV ($E_C \simeq 80$ MeV)

$X_{max} \simeq X_0 \ \ln (E/E_C) / \ln 2$

$h_{max} = h_0 \ln(X_A/X_{max})$ ➡ 5 km





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ASTRI and AIV

cherenkov telescope array

Astrofisica con Specchi a Tecnologia Replicante Italiana

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

MIUR

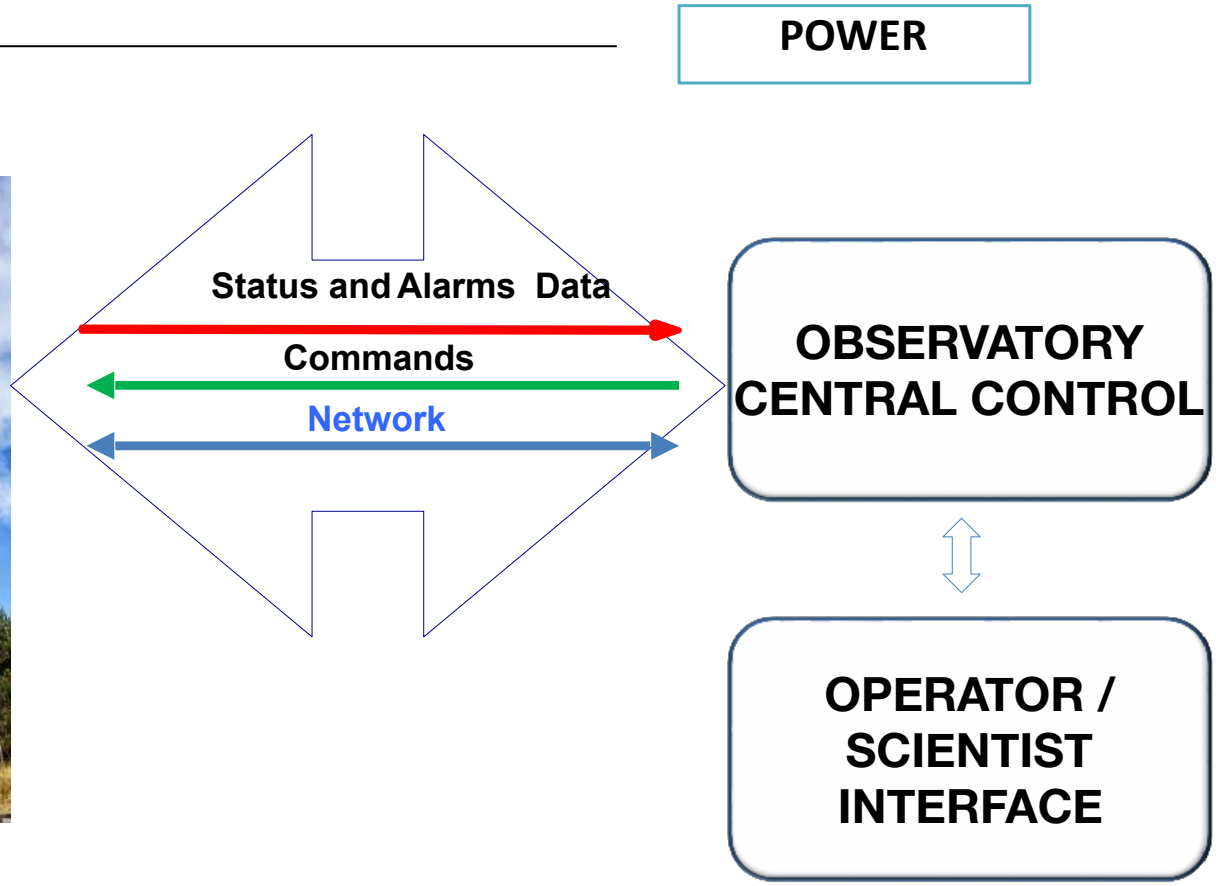
NORTH-WEST UNIVERSITY YUNIBESITI YA BOKONE-BOPHIRIMA NOORDWES-UNIVERSITEIT

Universidade de São Paulo

ASTRI-CTA

- **2011**
  Progetto bandiera del MIUR: ASTRI
- **2014**
  ASTRI SST-2M inauguration
- **2017**
  1° Cherenkov light
- **2018**
  ASTRI SST-2M dedicated to Horn D'Arturo
- **2019**
  pathfinder

ASTRI SST-2M



The ASTRI SST-2M is a stand-alone intelligent active machine programmed to receive commands, acquire and transmit scientific/engineering data, detect, signal and, where possible, recover from errors.

Contribution of OAS People to the ASTRI project

M. Trifoglio (team leader)

V. Conforti (Resp. DAQ, AIV Software)

A. Bulgarelli (Quick Look, framework)

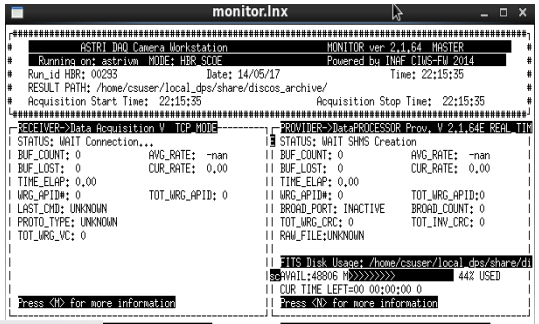
V. Fioretti (Resp. Quick Look)

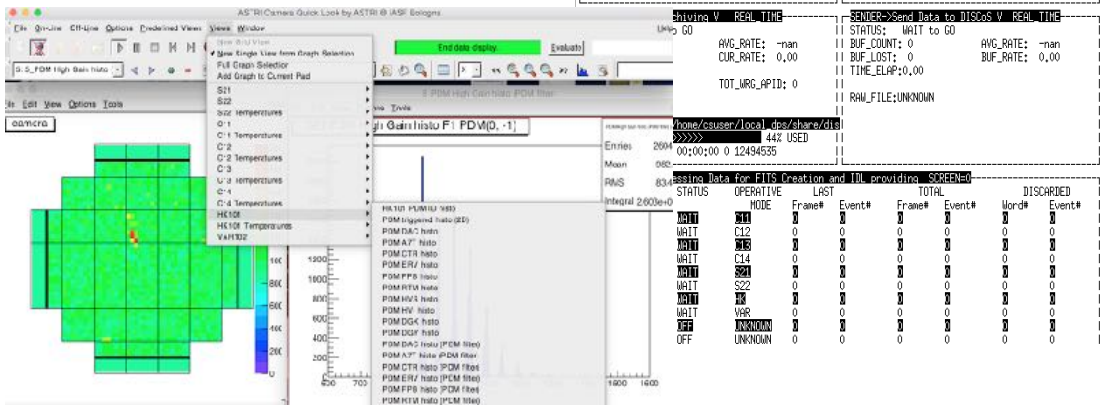
F. Gianotti (Resp. ICT)

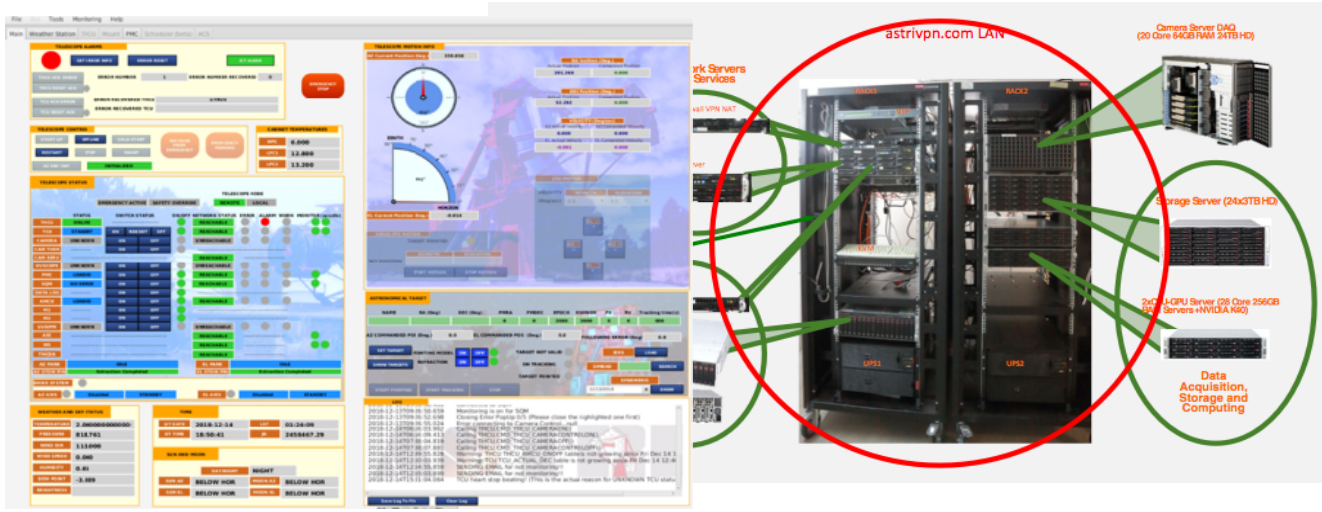
F. Russo (AMC, GUI)

A. Tacchini (ICT)

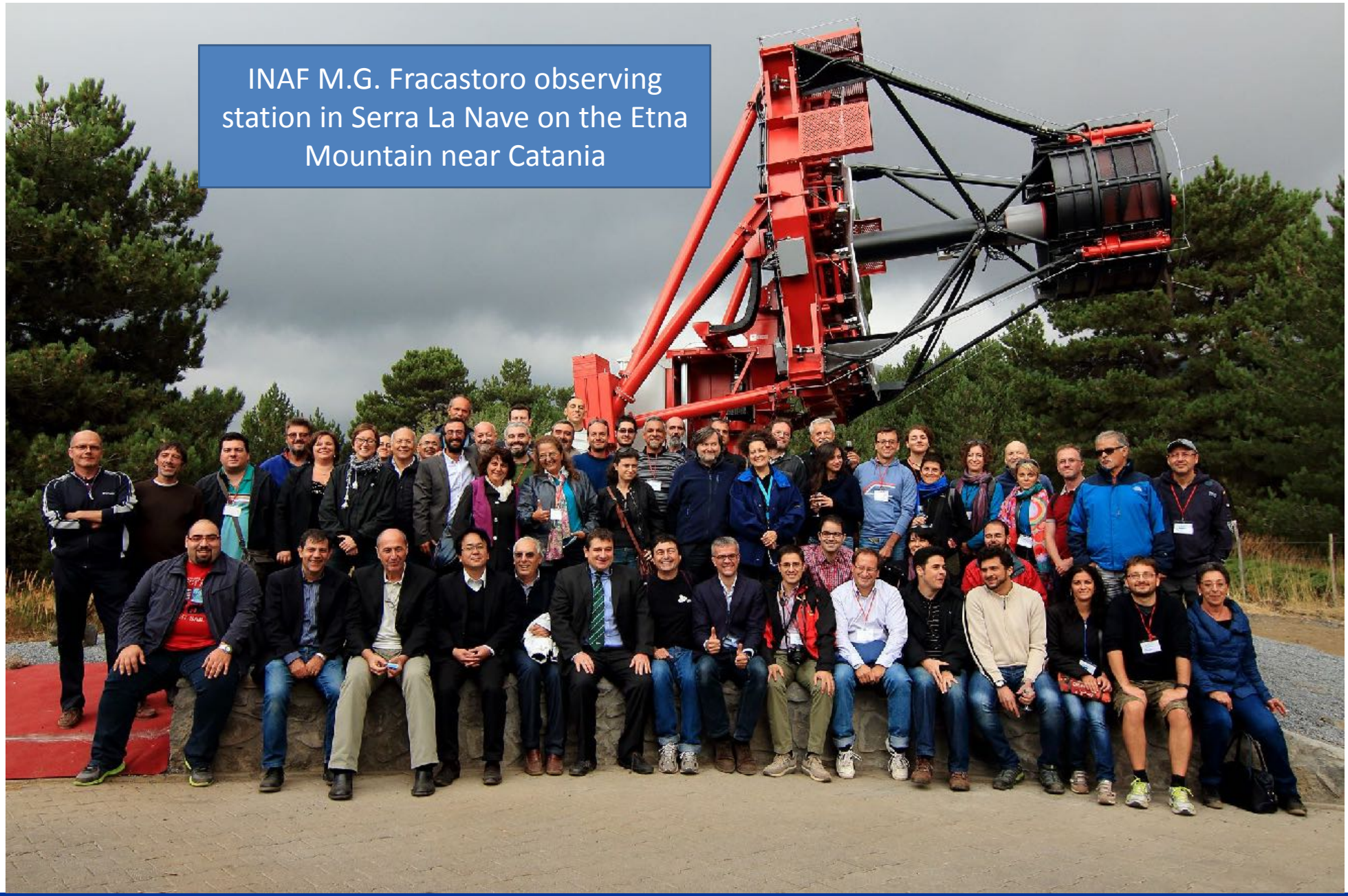
G. De Cesare







ASTRI SST-2M Inauguration - 2014



The future of ASTRI pathfinder in CTA

Implementation of a mini-array of 9 ASTRI SST-2M

- 9 ASTRI telescope & cameras + 1 spare camera (procurement via industrial contracts started)
- End to end: validation and commissioning of the array (including trigger and SW) through Cherenkov astronomical observations
- Commitment with the Italian government and international partners to build it
- Dedicated funding on top of the 50 M€ of the Italian contribution to CTA

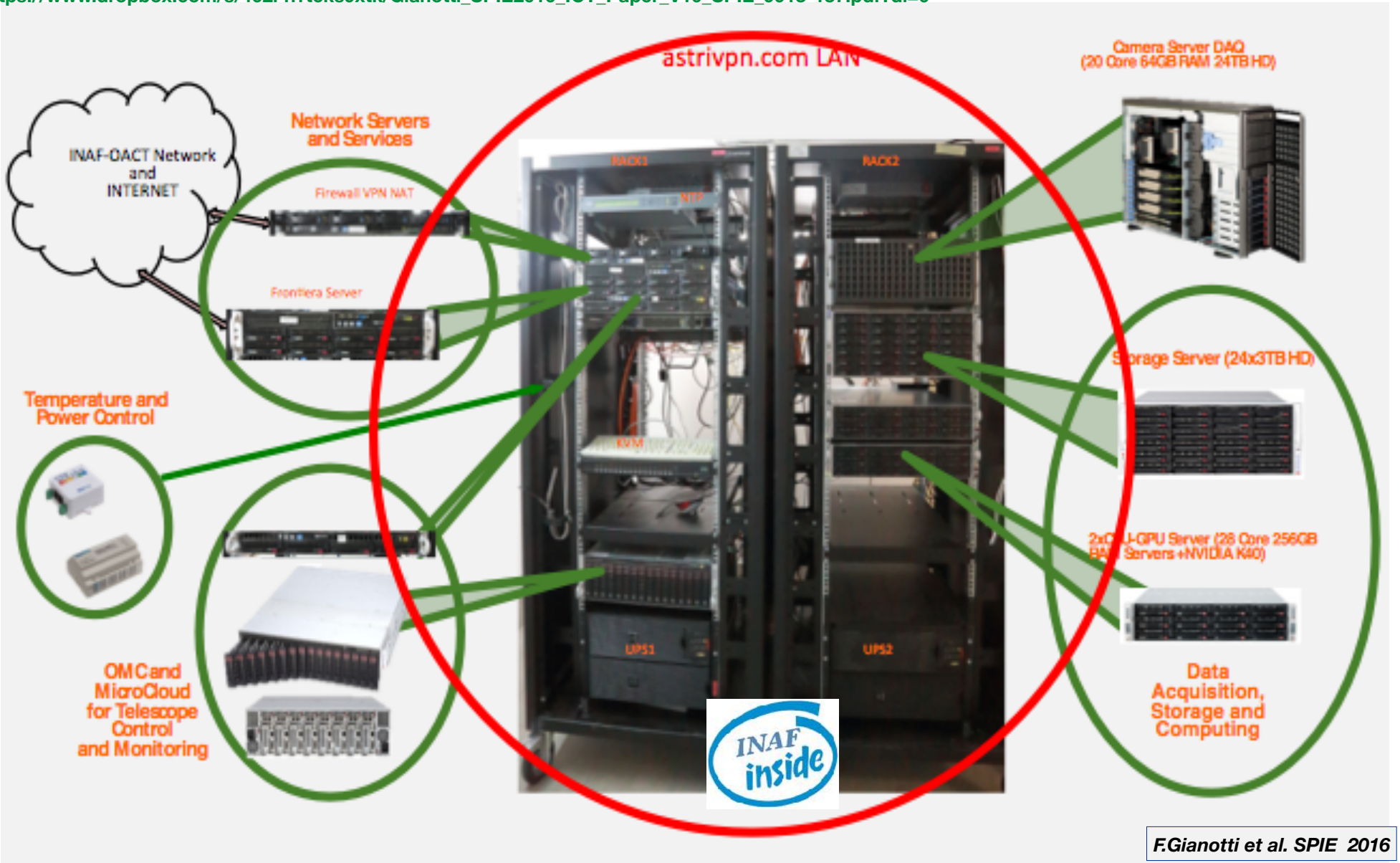
cherenkov telescope array

Computing Infrastructure

ASTRI Prototype: ICT Infrastructure

ASTRI-SST-2M ITC overall schema. This figure represents the current and almost definitive status of the ICT infrastructure of the ASTRI-SST-2M Telescope. It identifies the main elements that compose it

https://www.dropbox.com/s/462r1rrtcks9xtk/Gianotti_SPIE2016_ICT_Paper_V10_SPIE_9913-137.pdf?dl=0



F.Gianotti et al. SPIE 2016

cherenkov telescope array

Observatory Level Use Cases

Science-related and observatory Top Level Use Cases

- Leading of CTA Observatory Top Level Use Cases (A. Bulgarelli)
- Science use cases:
  - UC-SCI-001: Perform a long term **Monitoring of an AGN**
  - UC-SCI-002: Perform an **AGN Snapshot**
  - UC-SCI-003: Observe a **transient** discovered with **RTA** (Real-Time Analysis)
  - UC-SCI-004: Observe a ToO following an alert from **gravitational wave** observatories
  - UC-SCI-005: Observe a ToO following an alert from high-energy **neutrino** telescopes
  - UC-SCI-006: Observe a **GRB** after external alerts
  - UC-SCI-007: Observe an **XRB/gamma binary** from external alert
  - UC-SCI-008: Perform a **Survey** of a region of the sky
  - UC-SCI-009: Observe a **fixed position on the sky**
  - UC-SCI-010: Observe moon, planets and other celestial objects with **no fixed Ra/Dec**
  - UC-SCI-011: Take **Intensity interferometry on a star**
  - UC-SCI-012: Measure the spectrum of **Hadronic Cosmic Rays**
  - UC-SCI-013: Measure the spectrum of **VHE Cosmic Ray Electrons**
  - **UC-SCI-014: Observe a flaring AGN after external alerts**
- **Observatory use cases:**
  - **Main workflow of the CTA Observatory, from proposal to scientific analysis**
  - **“UC-CTAO-001: Observe with CTA” put observation and science-related use cases all together.**

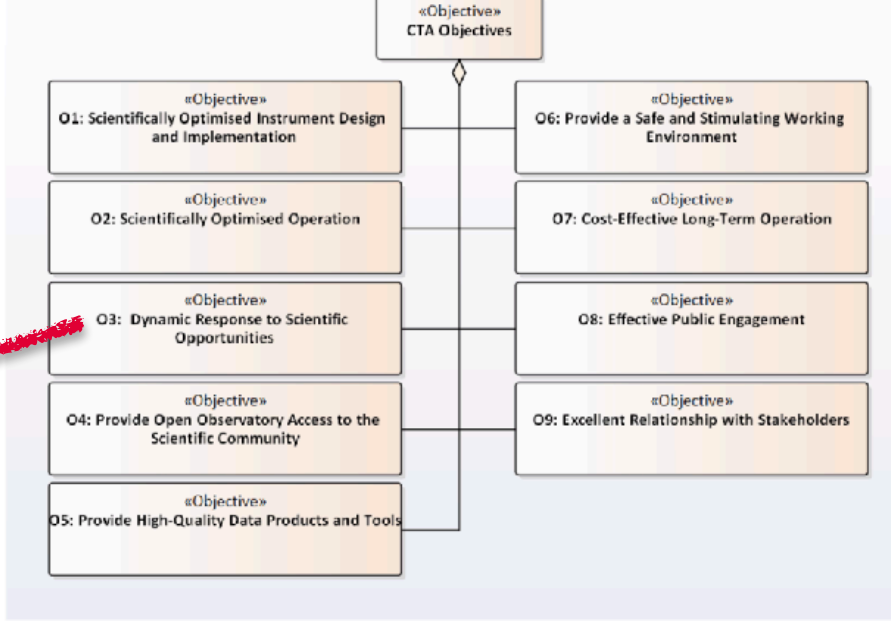
Scientific Pipelines: the CTA Real-Time Analysis (RTA)

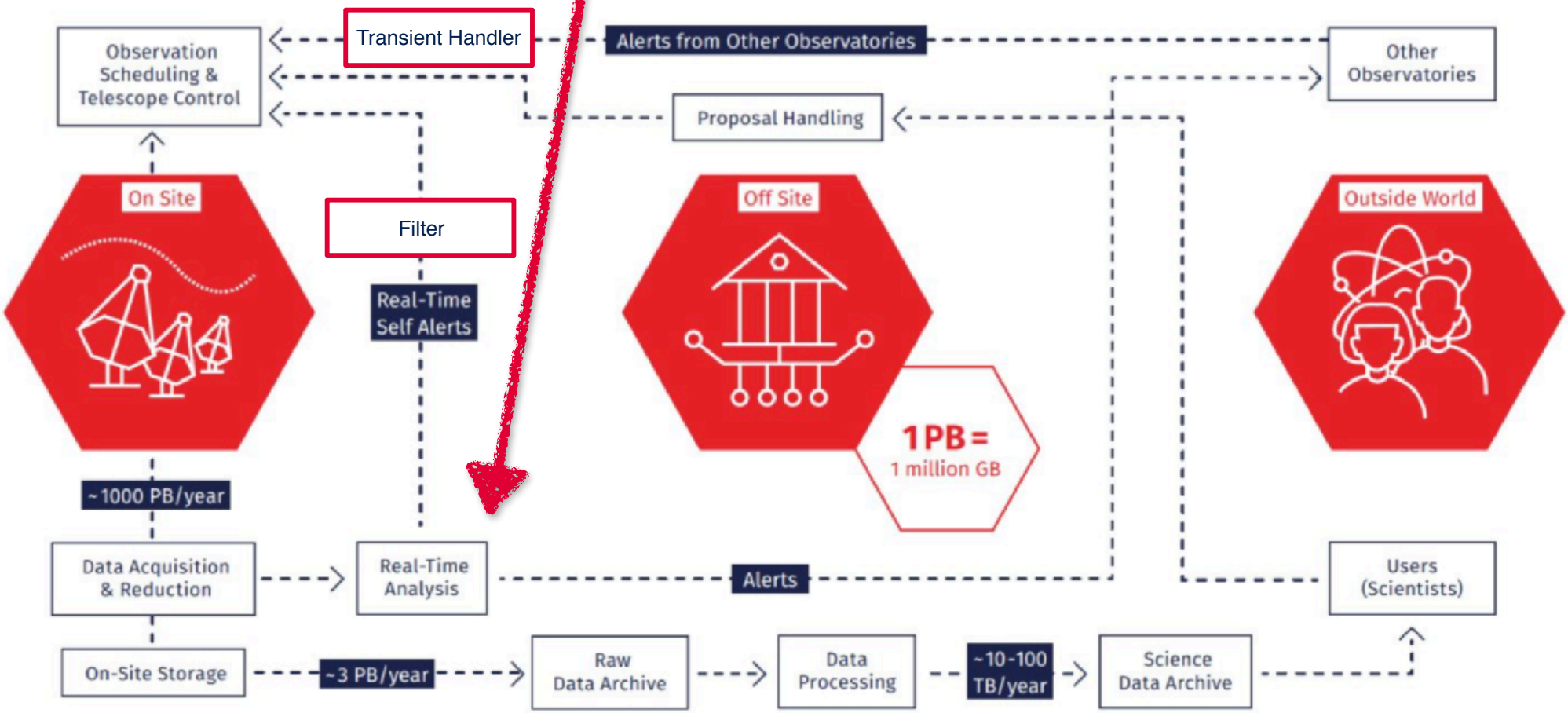
Contesto tecnologico

- **Nome progetto**: **pipeline di analisi dati scientifica per multi-messenger e multi-wavelength astronomy per osservatori di alta energia**
- Progetti: AGILE/ASI, CTA, ASTROGAM
- **Banda**: MeV, GeV, TeV
- Durata del progetto: progetto trasversale
- Ruoli: AGILE e CTA: responsabilità delle pipeline, AGILE: responsabilità Flare Advocate team, AGILE: Software coordinator, ASTROGAM: sviluppo pipeline
- **Tecnologie trasversali:** Big Data, Deep Learning, High Performance Computing, librerie software comuni
- **Outreach**: AGILEScience App for mobile phones, public lectures, media INAF
- Personale OAS coinvolto per la parte tecnologica: A. Bulgarelli (responsabile), AGILE e CTA: N. Parmiggiani, L. Baroncelli, V. Fioretti (consulenza scientifica). Solo CTA: G. De Cesare, A. De Rosa (sviluppo), V. Conforti, F. Gianotti, F. Russo (infrastuttura di sviluppo), L. Nicastro (database), E. Maiorano, G. Stratta, E. Torresi (validazione). Solo AGILE: M. Trifoglio, F. Gianotti. Solo ASTROGAM: N. Auricchio, A. De Rosa, V. Fioretti.
- Collaborazioni INAF: CTA Italia (M. Trifoglio spokesperson), F. D'Ammando (IRA), AGILE Team
- **Collaborazioni esterne:** Università di Modena (Dipartimento di Ingegneria), Università di Bologna (Dipartimento di Ingegneria, Dipartimento di Astronomia), Università di Padova (CISAS), OpenPOWER Foundation, CERN/OpenLAB, CTA Consortium & Observatory, ASTROGAM Consortium
- On-going **master thesis**: G. Zollino (Big Data), S. Tampieri (CTA Data Analysis, relatore C. Vignali)
- **PhDs**: N. Parmiggiani (PhD on Big Data), L. Baroncelli (PhD on Machine Learning),
- Additional PhD on Deep Learning (AGILE): A. Maccaluso
- Sviluppi futuri: competenze e software per pipeline scientifiche future high-energy X e gamma
- **Progetti collegati:** Monte Carlo simulation per telescopi spaziali, sistemi di acquisizione dati dai telescopi
- Talk OAS days:
  - (i) Day 1, 16.15-16.45 Bulgarelli "CTA"
  - (ii) Day 2, 15.00-15.30 Rossi / Stratta / Nicastro, "Studio multi-frequenza, da terra e dallo spazio, di transienti rapidi associati a GRB, GW e FRB e delle loro galassie ospiti" <- AGILE
  - (iii) Day 2, 16.30-16.40 Parmiggiani, Bulgarelli "Deep learning, Big Data and Open POWER Foundation activities for high-energy astrophysics"

Context

Issuing Alerts. The CTA Observatory must be capable of issuing alerts to other instruments within two minutes, on the basis of a Real Time Analysis, to maximise science return on transient and time-variable phenomena.





Functionalities

Manual or automated way.
With or without human intervention.

Data reconstruction

Data quality monitoring

Check the status of the observation

Science monitoring

Provide feedback to external triggers, to decide the strategy of the observation

Graphical User Interface for Astronomer on-duty/Data Quality scientist/Operator

For people.
Counts maps.
Light curve.

Generate science alerts

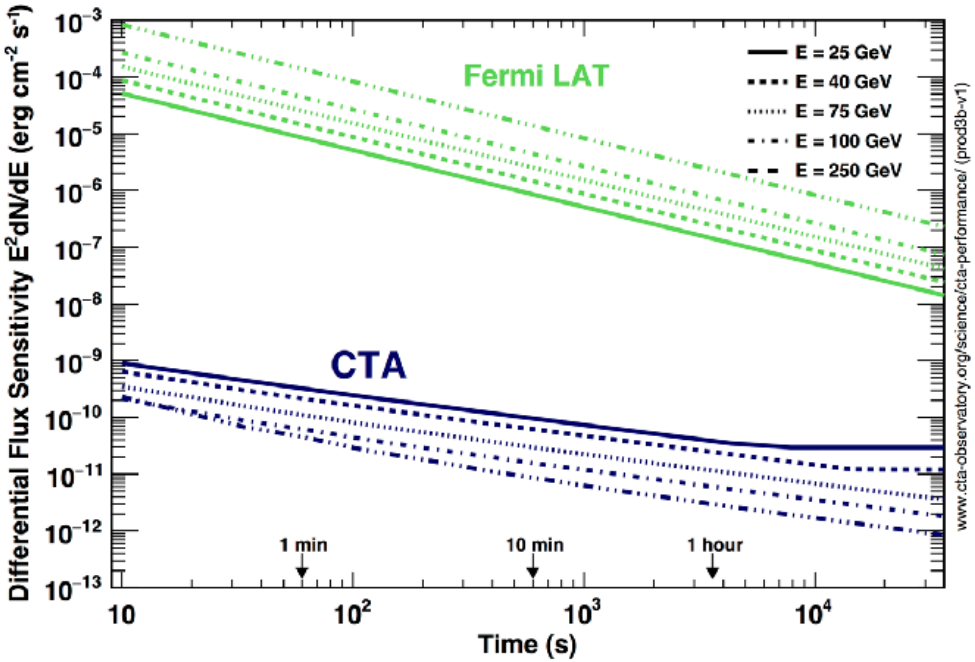
For internal and external communication

A possible order of priority.
First phase: manual
Second phase: automated

Main requirements and constraints

- The RTA must be capable of **issuing science alerts, with a latency of 30s**
- The RTA must **search for transient** and/ or time variable phenomena on fixed timescales **from 10 seconds to 30 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
- There will be an RTA pipeline **for each sub-array** running in parallel

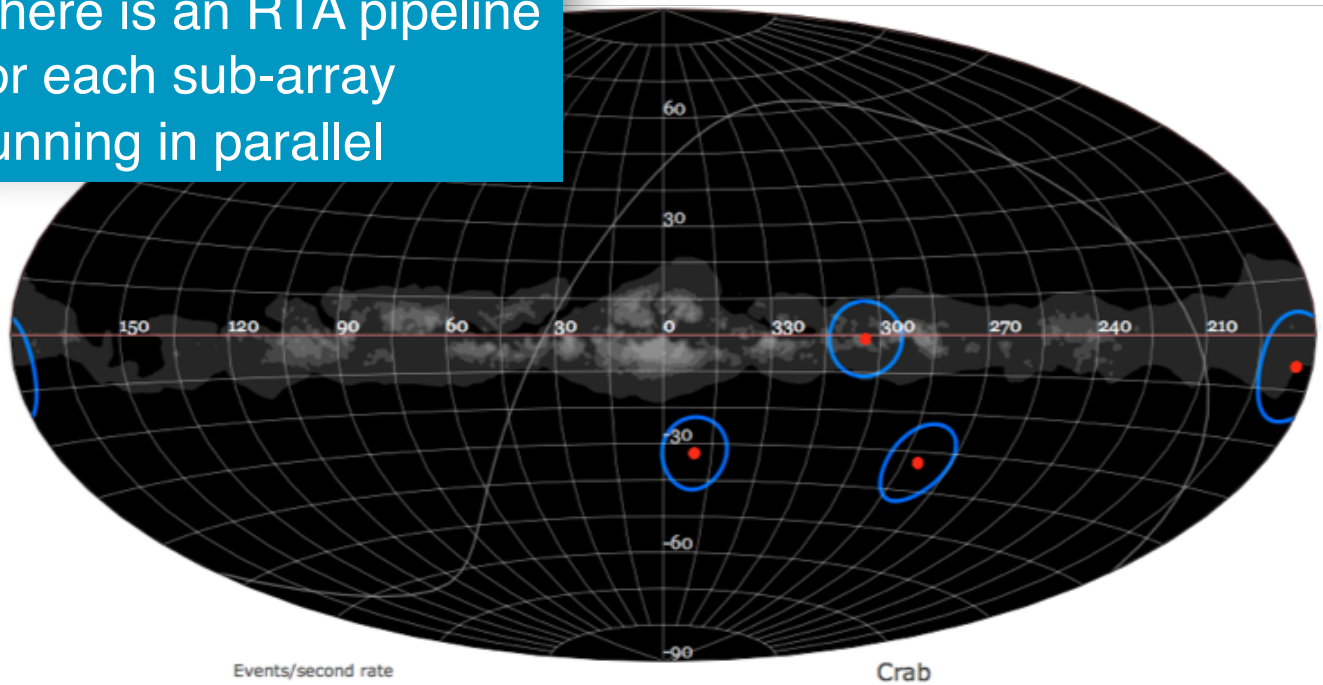
- Constraints:
  - **The data flow will be about 0.5 - 4 GB/s**
  - **The data rate spans from 600 Hz to 25000 Hz**



Leading of the **CTA ASWG short-term sensitivity WG** (V. Fioretti)

Flare Advocates/Support Astronomer

There is an RTA pipeline for each sub-array running in parallel



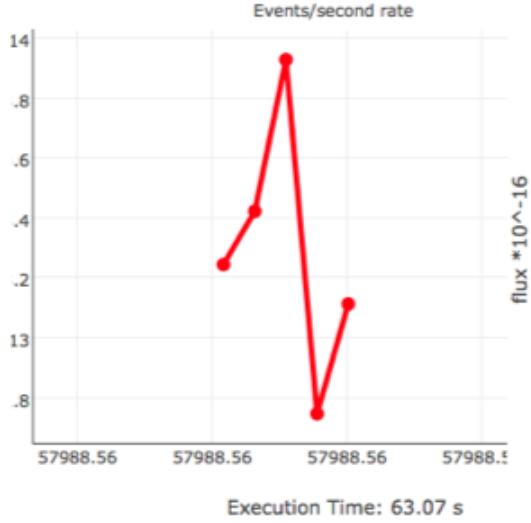
Show 10 entries Search:

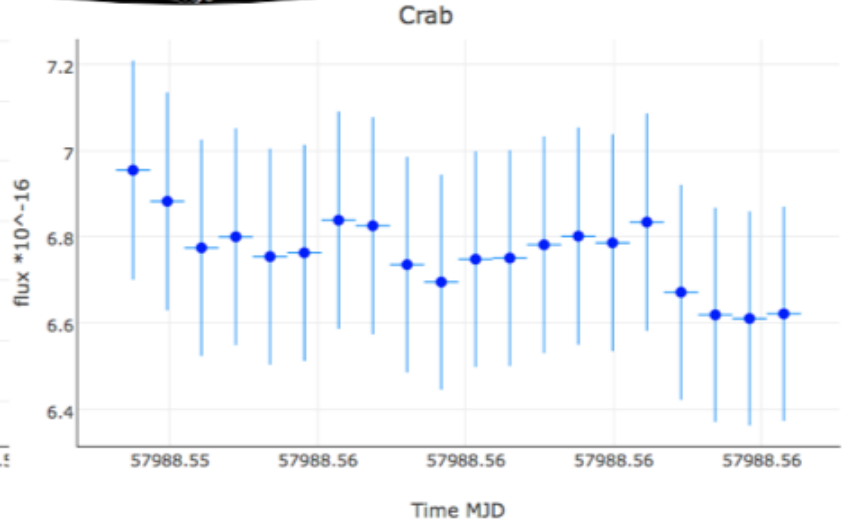
Name	Ra	Dec	Fov
Crab	83.63	22.01	10
LMC-N132D	81.26	-69.64	10
PKS 2005-489	302.37	-48.84	10
PSR B1259-63	195.69	-63.83	10

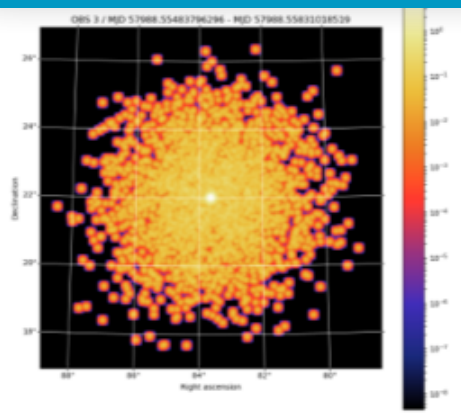
Showing 1 to 4 of 4 entries Previous 1 Next

The RTA for Support Astronomer

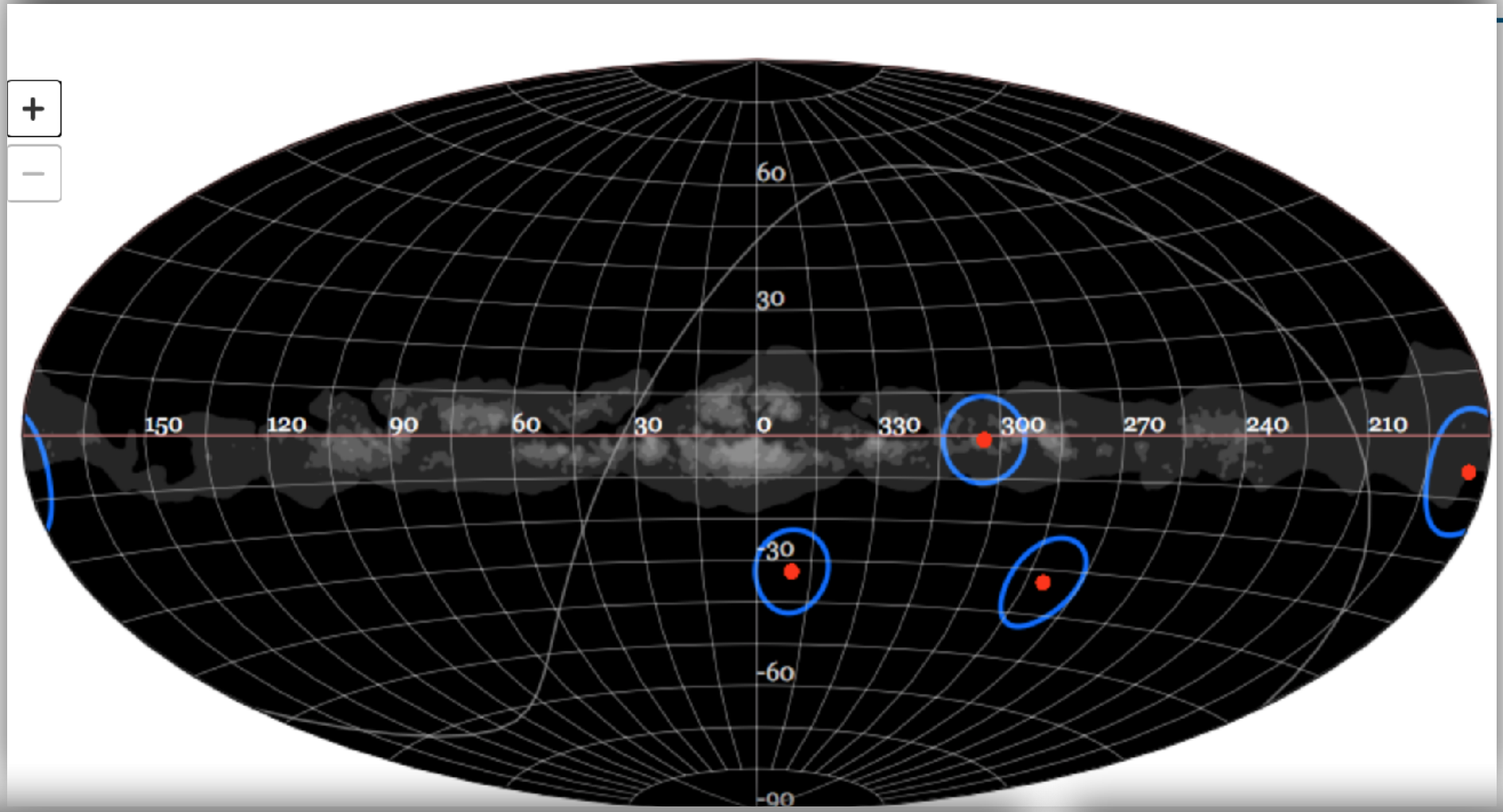
Full access to RTA results.







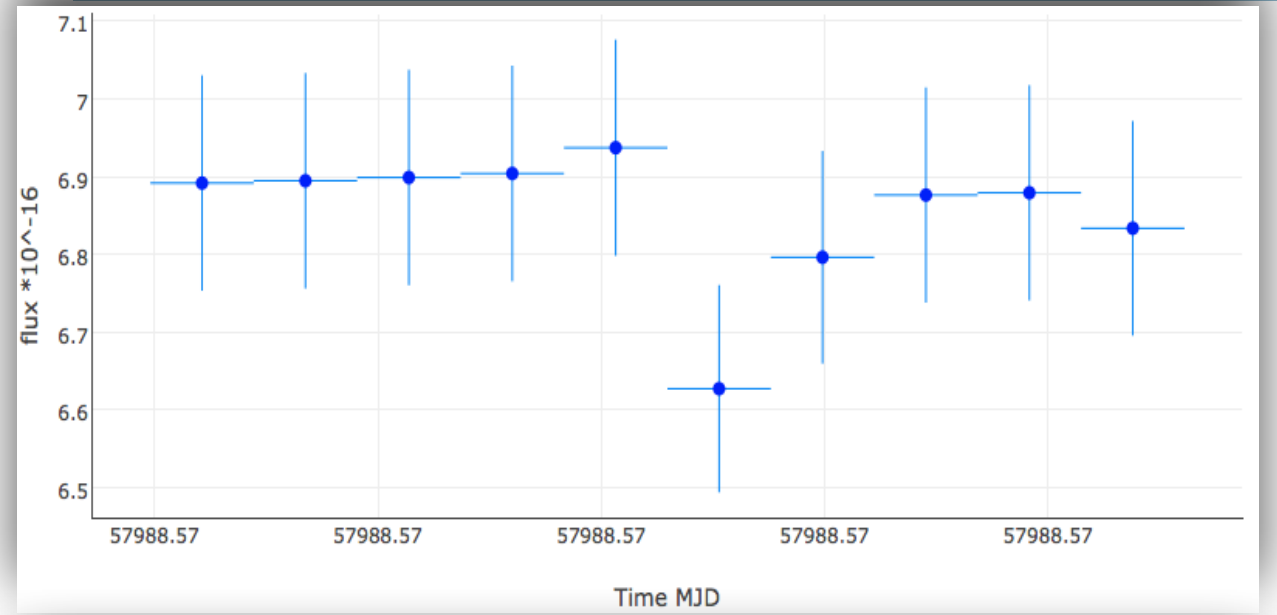
Multiple observations in parallel

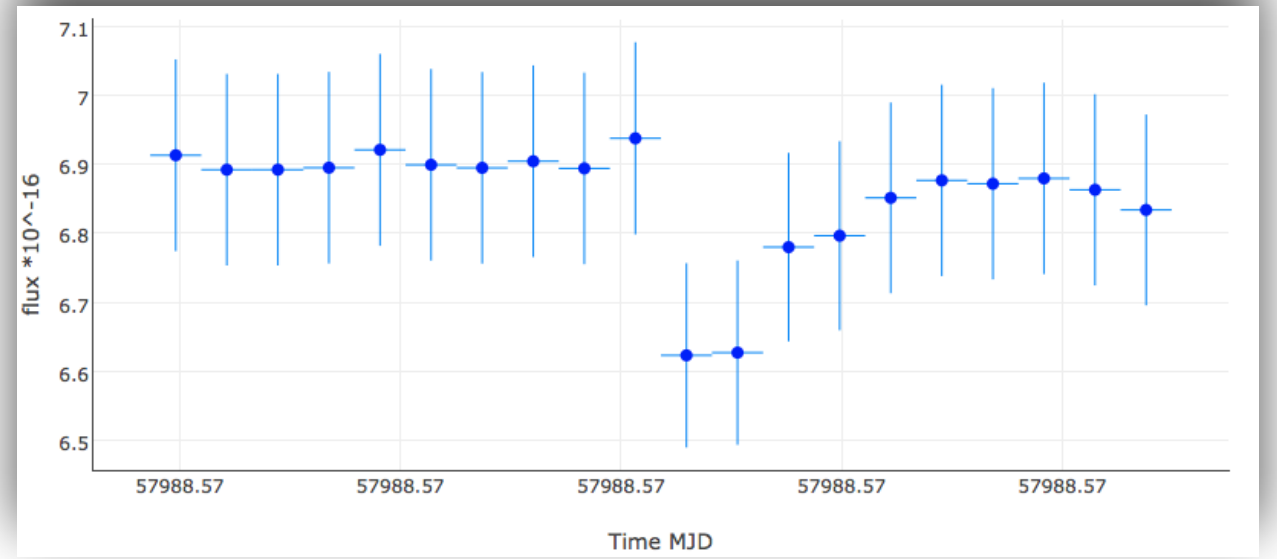


Subarray Operation: The RTA must permit the operation for independent sub-arrays at the same time, formed from distinct subsets of available Telescopes at a given Array site.

There is an RTA pipeline for each sub-array running in parallel

Multiple timescale analysis in parallel

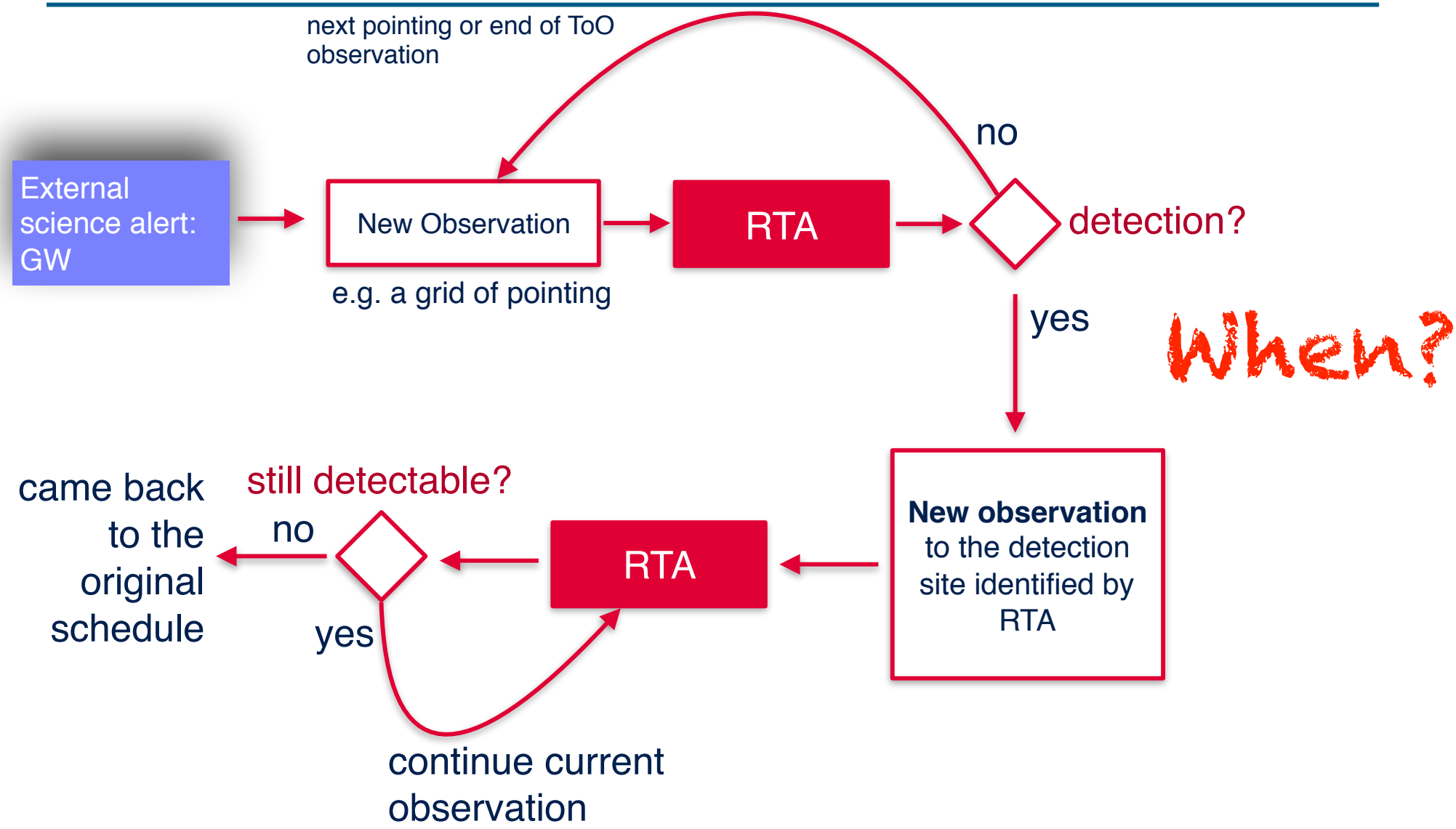




Transient Search Timescales: The RTA must search for transient and/or time variable phenomena on fixed timescales from 10 seconds to 30 minutes.

The search for transient phenomena is performed on multiple timescales on the same target/source

Change of the observation strategies in real-time

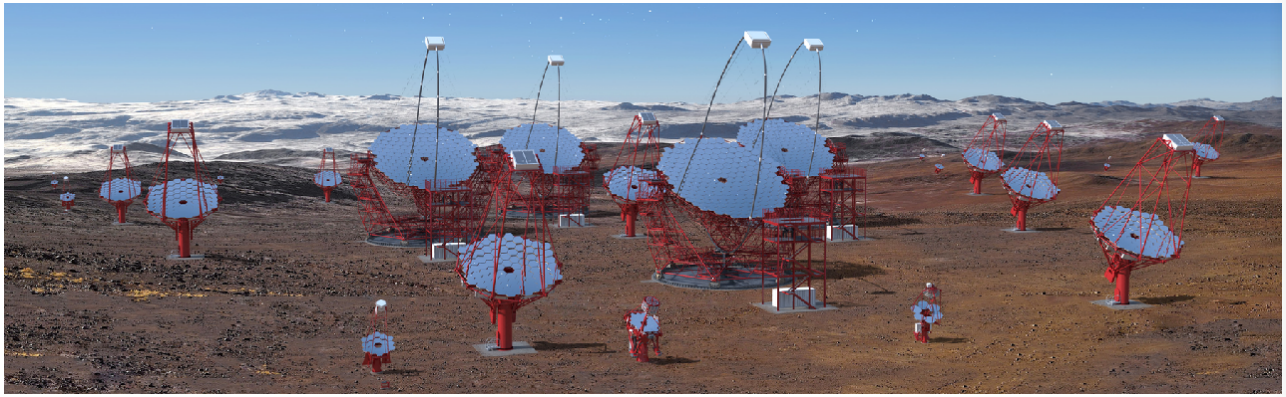


Scientific strategies... by example: GW

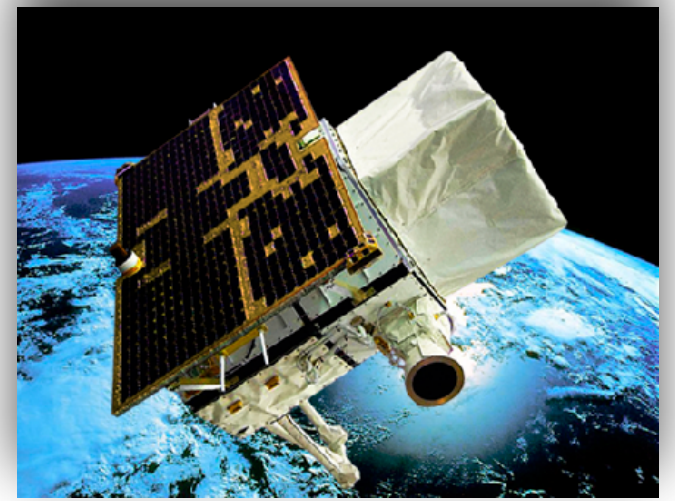
Current prototypes

ASTRI @ Serra La Nave (Etna)

LST1 @ La Palma



Full CTA on simulated data



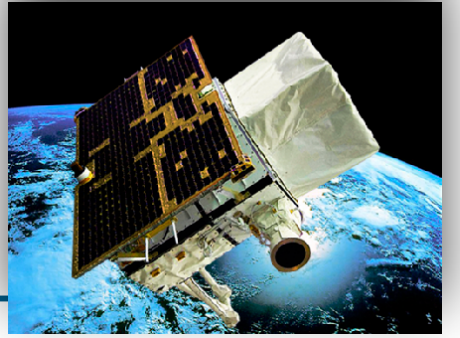
AGILE satellite

cherenkov telescope array

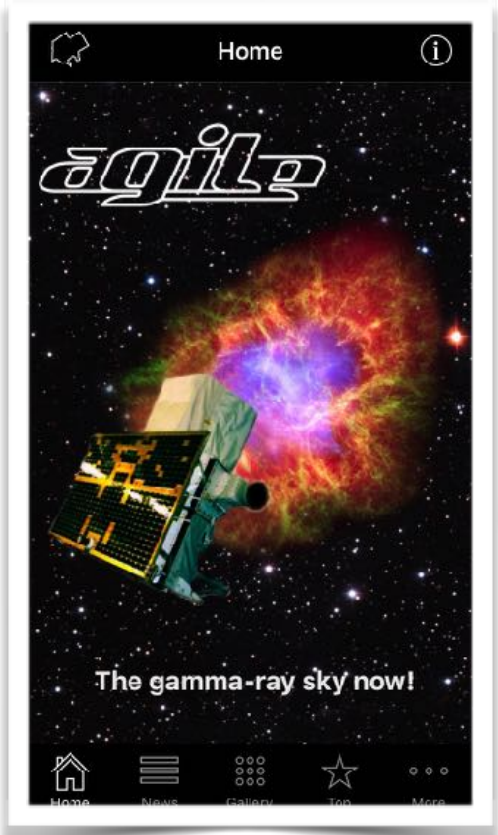
The core: the AGILE real-time analysis pipeline

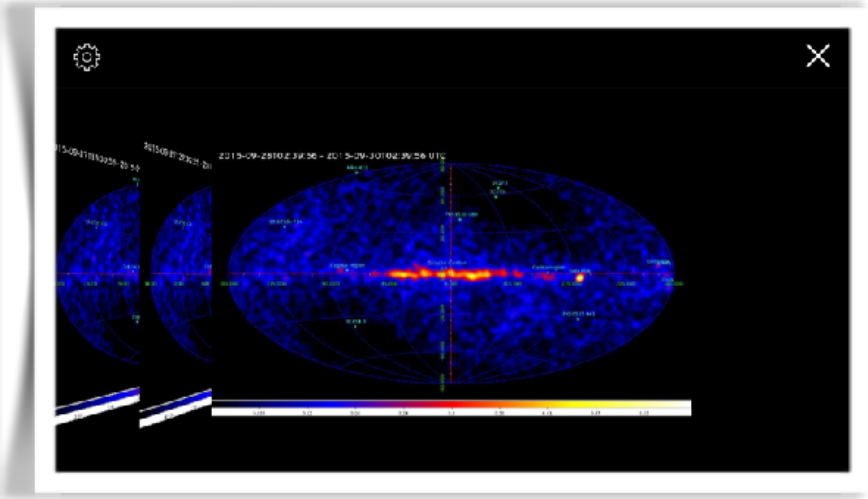
Main developer: N. Parmiggiani, L. Baroncelli

The core of this prototype is running for AGILE pipeline



- The core of the CTA prototype is the current AGILE real-time analysis, still under development for LIGO/VIRGO O3 campaign
- The pipeline receives external alerts from GCN network and LIGO/Virgo and process the AGILE data in real-time to detect AGILE counterparts.
- AGILE Software coordination and Leading of AGILE Flare and Burst Advocate team

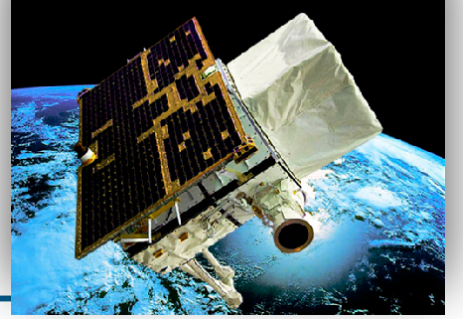




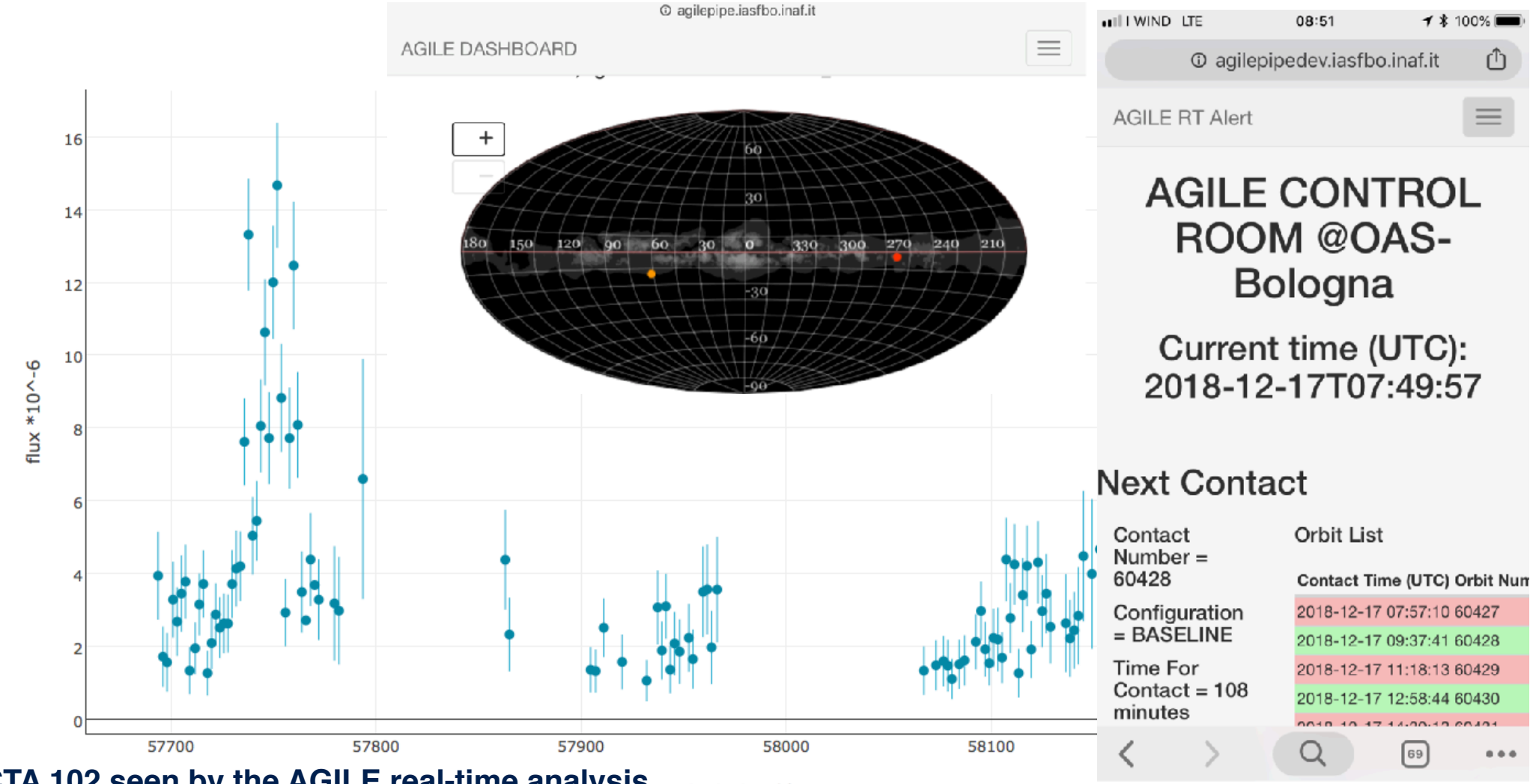
Check the AGILE gamma-ray sky in real-time from your mobile phone

Download the App to see the gamma-ray sky now:
https://itunes.apple.com/it/app/agilescience/id587328264?mt=8
https://play.google.com/store/apps/details?id=com.agile.science&hl=it

On-line determination of science alerts and related light curves from AGILE data



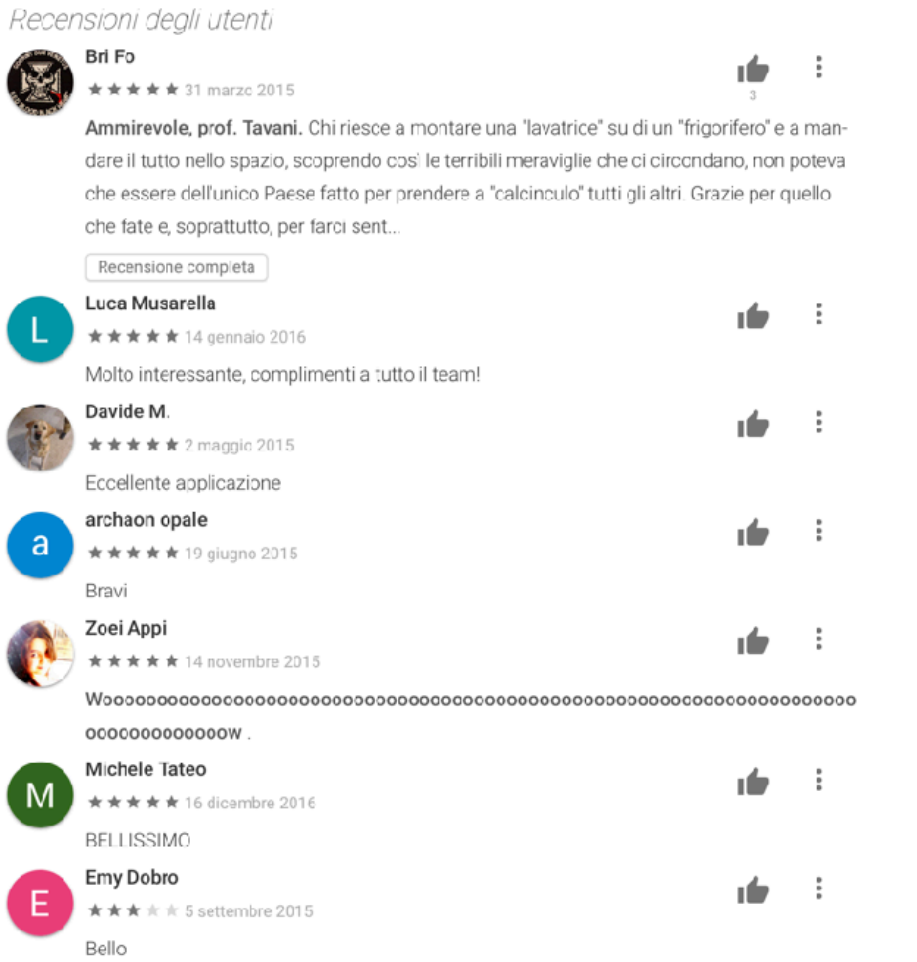
- On-line determination of science alerts and related light curves from AGILE data. A decision tree generate a science alert to the AGILE team via SMS and e-mail
- For Deep Learning results: see tomorrow afternoon talk

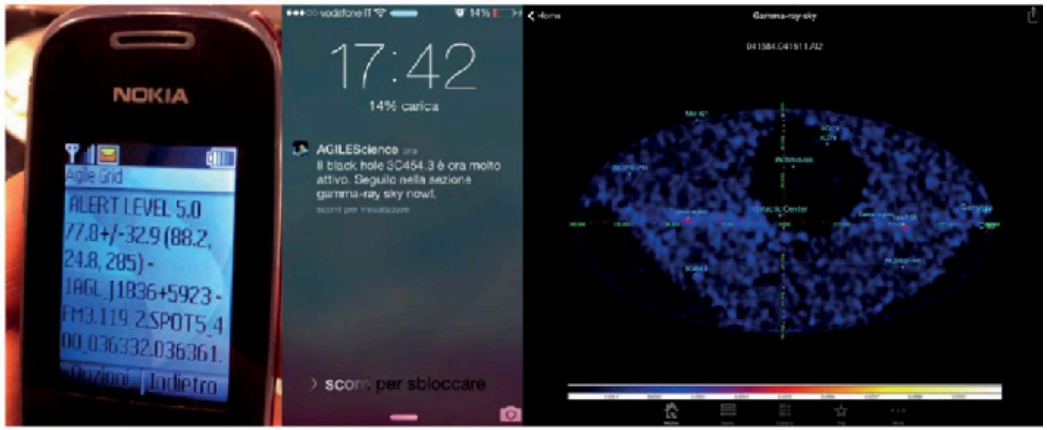


CTA 102 seen by the AGILE real-time analysis

On YouTube, App Store and Google Play

- CTA Real-Time analysis on YouTube:
  - https://youtu.be/C1vbgl7LwfQ (data streaming)
  - https://youtu.be/S3H67eqS9Dc (CTA, multiobs)
  - https://youtu.be/neiSg1e9Pj8 (ASTRI, Crab)
- AGILE
  - https://www.youtube.com/watch?v=u37-D55SZu8 (3C 454.3)
  - https://www.youtube.com/watch?v=9C2oM2WBJS0&t=13s (Crab Nebula flare)
  - More videos. Download the Apps (developer N. Parmiggiani):
    - https://itunes.apple.com/it/app/agilescience/id587328264?mt=8
    - https://play.google.com/store/apps/details?id=com.agile.science&hl=it
  - News on MEDIA INAF, in particular
    - SMS dallo spazio (F. Gianotti)
    - Apps and gamma-ray sky now (A. Bulgarelli, N Parmiggiani)





Dagli SMS alle notifiche *push* e alle mappe del cielo gamma sul *tablet*. Nel corso degli ultimi anni la tecnologia *mobile* si è evoluta ed ha cambiato il nostro modo di lavorare e di vivere. Abbiamo cercato di seguire questa evoluzione per massimizzare il ritorno scientifico di AGILE.

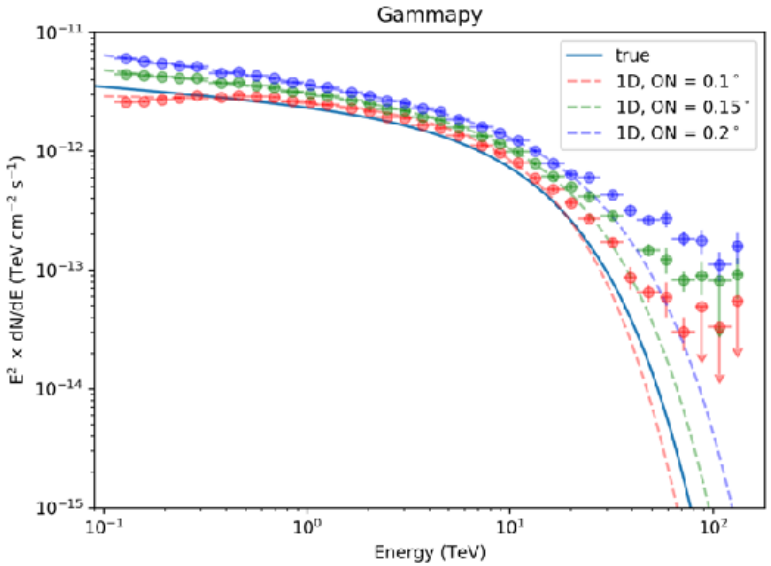
A. Bulgarelli, AGILE e l'astrofisica in tempo reale, Le Stelle 149

cherenkov telescope array

Data Challenges and Scientific Validation

CTA DC1

- **Goal**: comparison of the scientific outputs of the science tools - ctools and gammapy - developed for the CTA data analysis.
- **Dataset**: large Monte Carlo simulations in different astrophysical contexts (Galactic Plane, Galactic Centre, Extragalactic surveys and AGN monitoring).
- **OAS contribution**: Galactic Centre (GC) source analysis with gammapy (Giovanni De Cesare)
- **Results**: a complex region like the Galactic Centre requires a 3D analysis that takes into account of the different components.
    - The gammapy classical 1D on-off analysis yields results inconsistent with the Monte Carlo truth and strongly dependent on the size of the extraction radius. This difference is explained by the fact that the source flux that we measure is given by the sum of the GC source and other overlapping components that fall into the extraction region, most notably diffuse emission. The 3D analysis was not yet implemented in gammapy during the DC-1 activities.



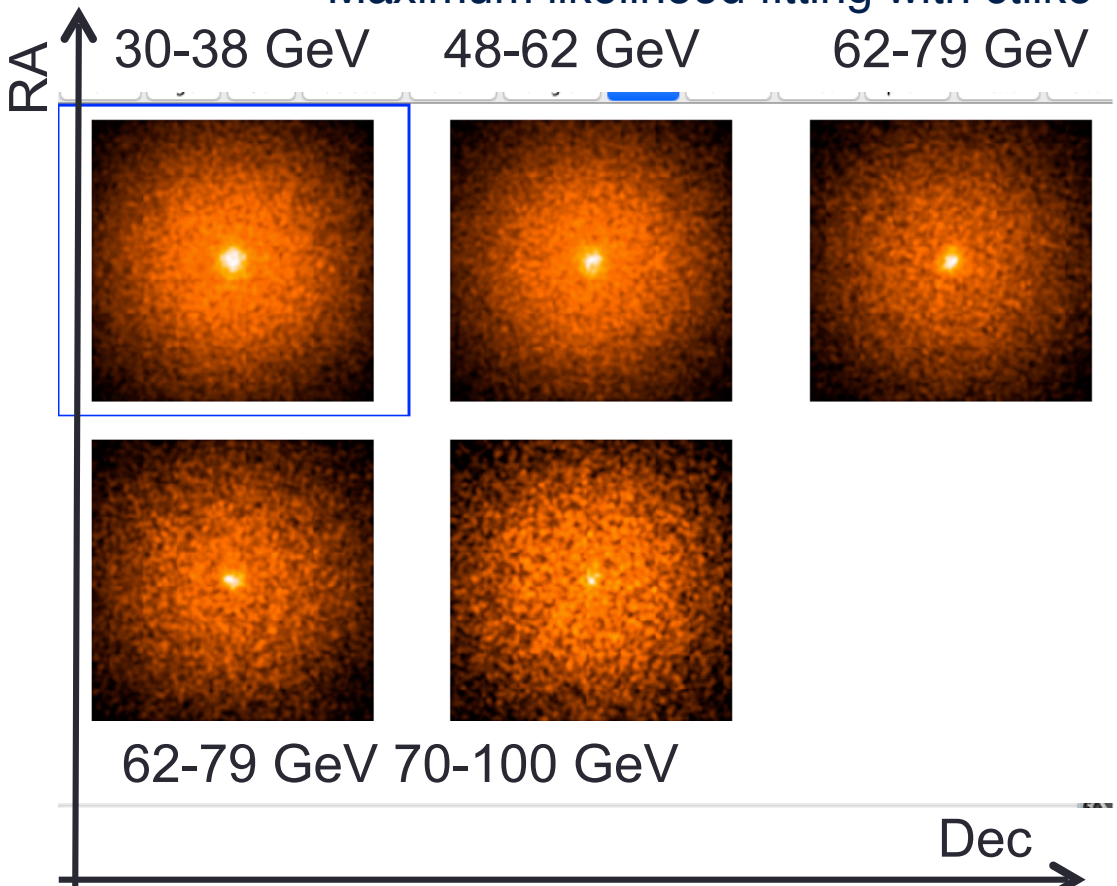
reconstructed SED of the GC source compared to the Monte~Carlo truth; the SED is reconstructed both over the full energy range assuming that it is described by an exponential cutoff power law. The SEDs are shown for different values of the size of the source region.

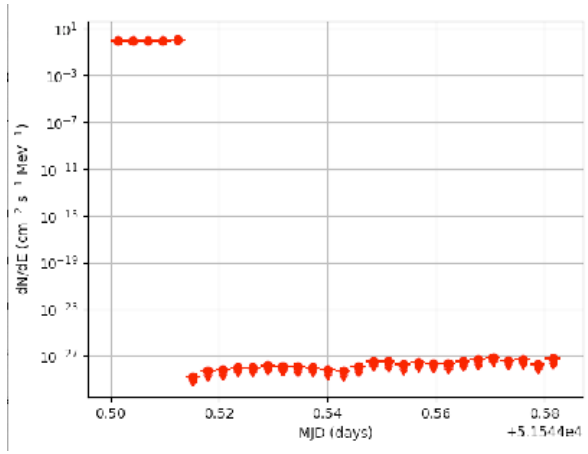
courtesy of G. De Cesare

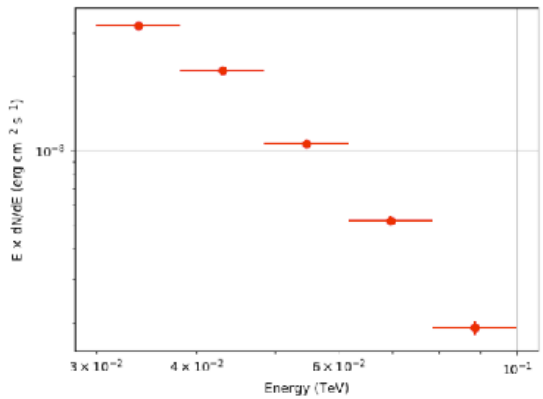
GRB Simulation: off-line analysis

Step-by-step off-line test of online RTA analysis:

1. simulations of transient source CTA observations with ctobssim → event lists
2. Each event list is divided into temporal bins with ctselect
3. For each temporal bin:
   - Generation of count map with ctbin
   - Maximum likelihood fitting with ctlike







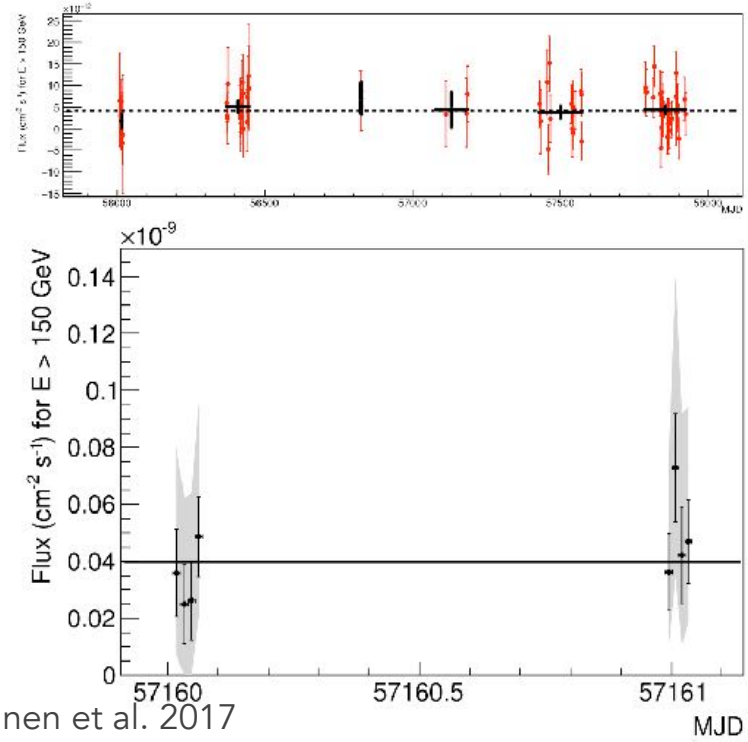
courtesy of Giulia Stratta

TeV variability

*Different TeV **variability time scales** observed with IACTs, both for blazars and for radio galaxies, indicate different **sizes** of the emitting region.*

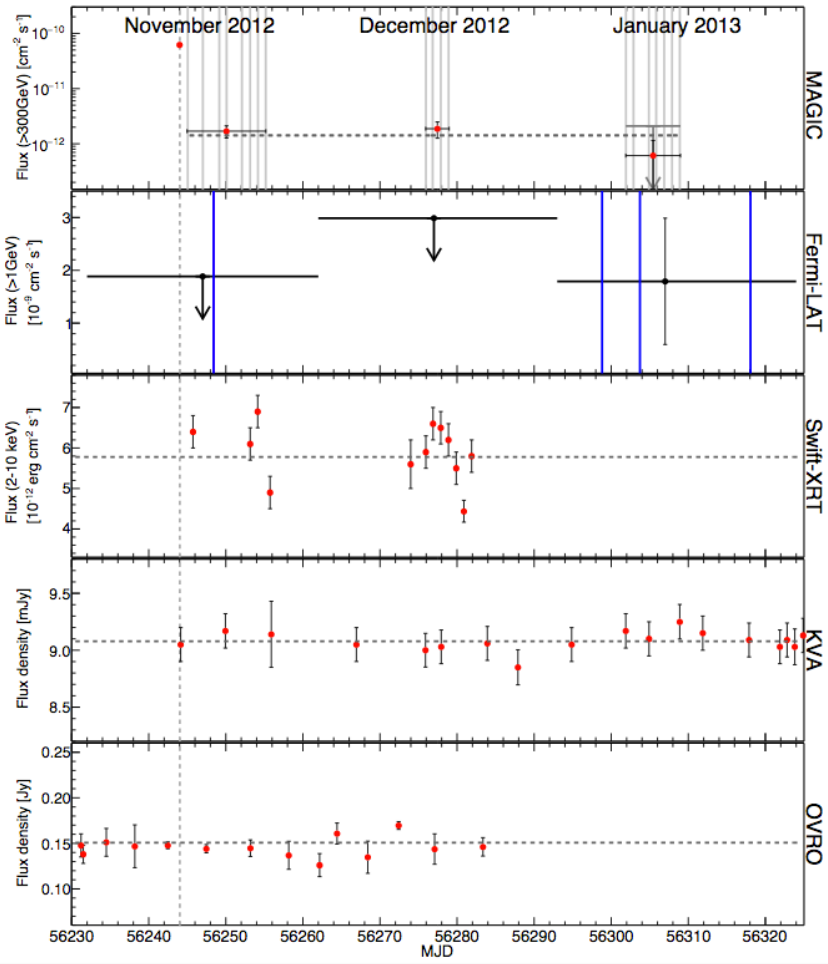
PKS1510-089 *Δt=20 min*

MAGIC Collaboration 2018



Ahnen et al. 2017

IC 310 *Δt=4.8 min*



courtesy of Eleonora Torresi & Filippo D'Ammando

Conclusions

- On-going activities on ASTRI, pathfinders, real-time analysis pipeline
- Ask listed people in this talk for more info