Gamma-Ray Bursts

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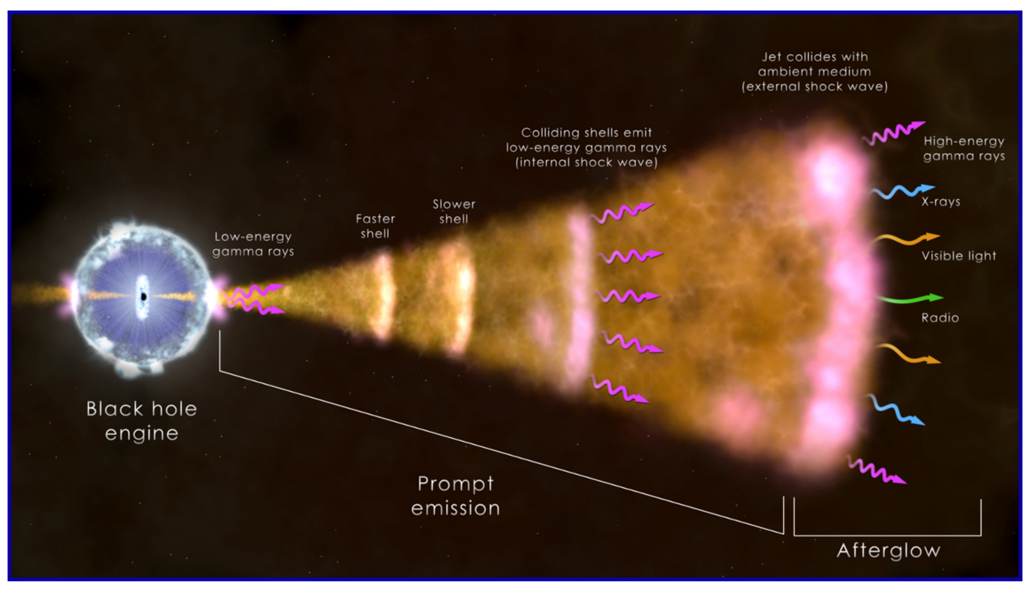
Gamma-Ray Burst

Gamma-Ray Bursts (GRBs) are powerful explosions in our Universe which have their major emission in the gamma-ray band. In fact, while they are on they outshine all other sources of the sky even though they are located at cosmological distances.



FIREBALL

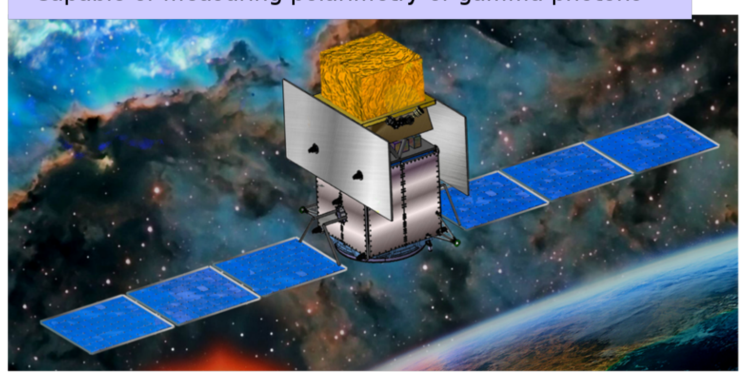
There are two possible progenitors for the GRBs: a collapsing massive star or two merging compact objects. In both scenarios a highly relativistic and collimated jet is emitted along the rotation axis of the residual central engine (possibly black holes).

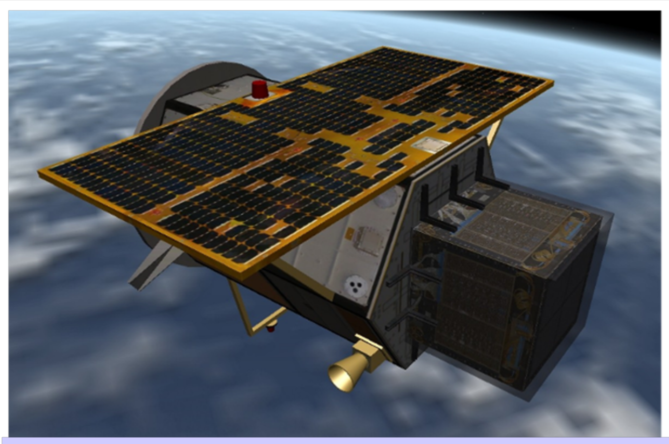
Particles, in particular electrons, are accelerated in internal shocks and produce the **prompt** GRB emission in the hard X-ray and soft gamma-ray bands via Synchrotron and Inverse Compton processes. This phase can last from few milliseconds to tens of minutes.

After the prompt emission, the outflow propagates and interacts with the external medium for many weeks. During this phase, called **afterglow**, the GRB can be localized with enough precision to associate it to the host galaxy in order to estimate its redshift. The afterglow ist presently observed in the X, optical and radio energy bands.

INSTRUMENTS

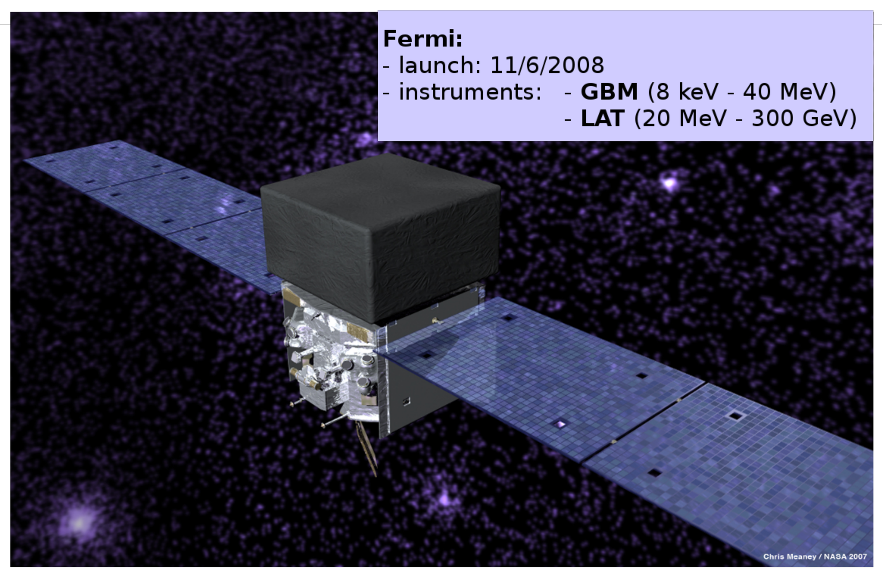
e-Astrogam
- Energy range : from 0.3 MeV to 3 GeV;
- Capable of detecting both Compton and pair particle creation events;
- Capable of measuring polarimetry of gamma photons





AGILE (Astro-Rivelatore Gamma a Immagini Leggero)
- launch: 23/4/2007
- instruments: - GRID: (30 MeV - 50 GeV)
  - SuperAGILE: (18 - 60 keV)
  - MCAL: (50 keV - 100 MeV)

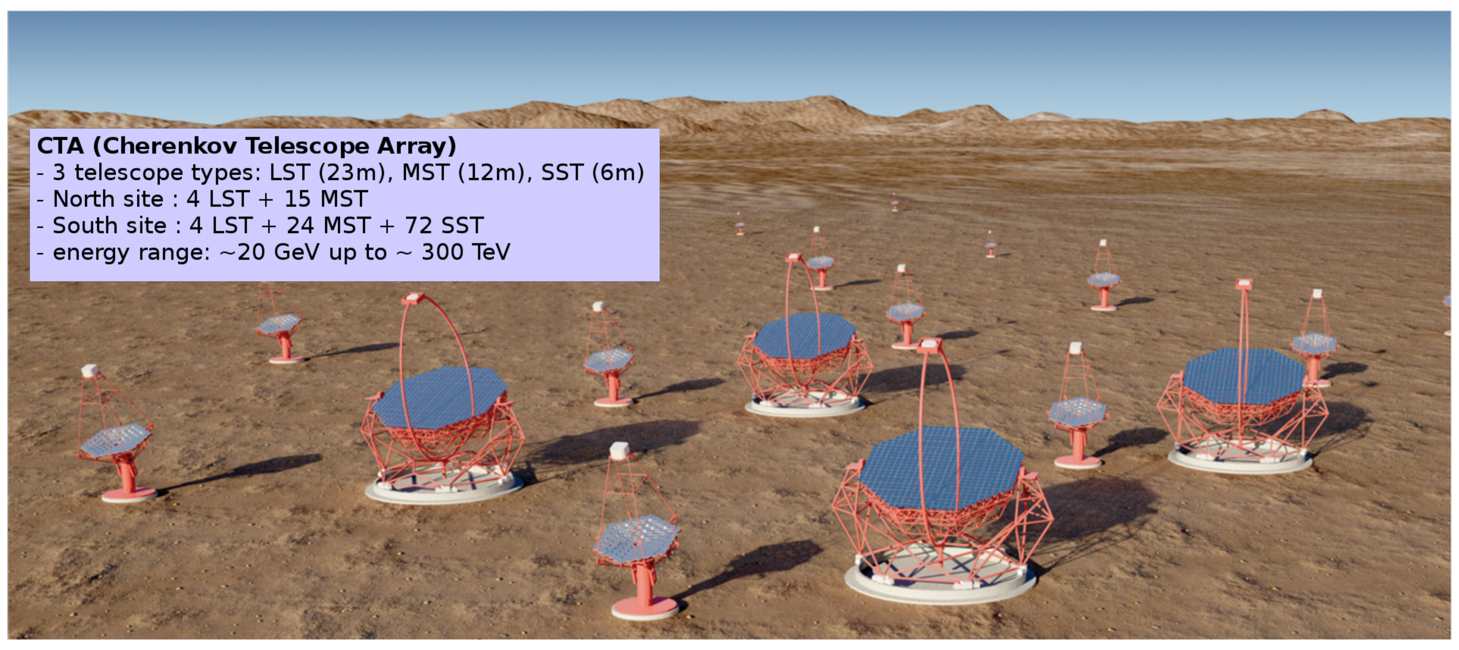
Fermi:
- launch: 11/6/2008
- instruments: - **GBM** (8 keV - 40 MeV)
  - **LAT** (20 MeV - 300 GeV)



---- FUTURE INSTRUMENTS ----

---- PRESENT INSTRUMENTS ----

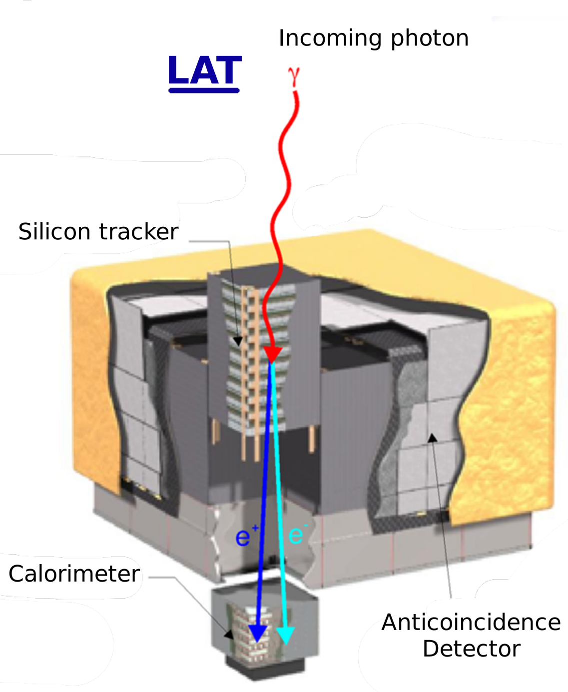
CTA (Cherenkov Telescope Array)
- 3 telescope types: LST (23m), MST (12m), SST (6m)
- North site : 4 LST + 15 MST
- South site : 4 LST + 24 MST + 72 SST
- energy range: ~20 GeV up to ~ 300 TeV



MAGIC (Major Atmospheric Gamma Imaging Cherenkov)
- energy range: 50 GeV - 100 TeV
- diameter: 17 m
- stereo configuration

DETECTION METHODS

Pair production



The Large Area Telescope (LAT) is designed to detect gamma rays via the pair production mechanism.

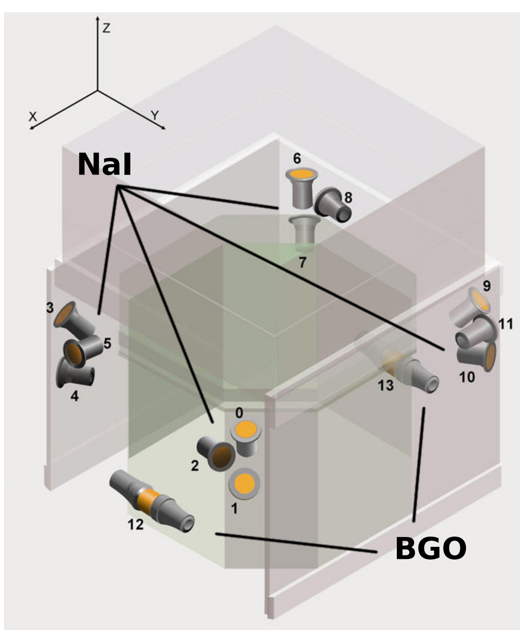
LAT is composed by a **tracker-converter** made of silicon and tungsten layers, an **electromagnetic calorimeter** (CsI) and an **anticoincidende detector** that covers the whole structure, used to discriminate photons from background cosmic rays.

The incoming photon interacts in the tungsten layer and is converted in an electron-positron pair, which is tracked by the silicon detectors.

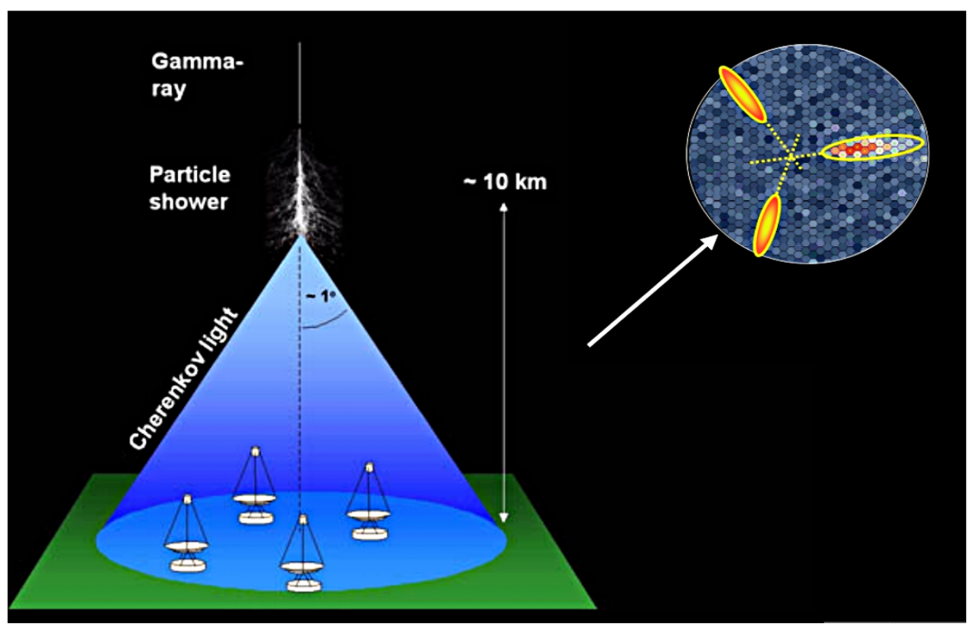
The two particles then interact with the calorimeter and produce an electromagnetic shower.
As a final result we obtain the incoming direction and the energy of the photon.

GBM

The Gamma-Ray Burst Monitor (GBM) is composed by 12 NaI and 2 BGO scintillator detectors.
A group of three NaI is located at each corner of the Fermi structure pointing at three different directions, whereas one BGO points the Sun and the other watches the opposite direction.
The detection using scintillator is suitable in the keV energy range, up to few tens of MeV.



IACT (Imaging Atmospheric Cherenkov Telescopes)



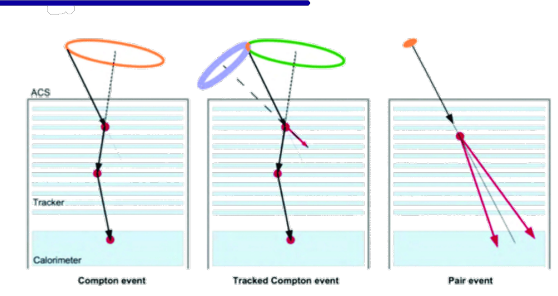
The detection of gamma rays using Imaging Atmospheric Cherenkov Telescopes (**IACTs**) is possible thanks to the Cherenkov effect: the incoming gamma-ray, interacting with the atmosphere, produces an **electromagnetic shower**. These particles travel faster than light in air, and so emit a characteristic blue light (up to the UV band), called **Cherenkov radiation**.

The Cherenkov light from all the shower is collected by **large mirrors** and focused on a camera made of many **photomultipliers** (PMTs), which converts the photons into an electrical signal.

The image produced in the camera has an elliptical shape, that can be studied in order to reconstruct the arrival direction and the energy of the primary photon. A better angular resolution and sensitivity can be achieved using more than one telescope in the so called **stereoscopic configuration**.

In this framework, **Monte Carlo** (MC) simulations are extremely important in order to discriminate between showers produced by gamma-rays and cosmic rays and to find the energy of the primary particle.

e-ASTROGAM

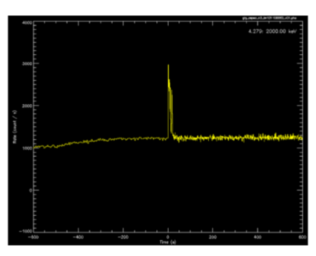


Like other gamma ray telscopes, eAstrogam consist of three main detectors: a **Tracker** made of several SI thin layers of double sided strip detectors (DSSD), a **Electromagnetic Calorimeter** made of an array of CsI scintillation crystals and a **Anticoincidence System** realized with plastic scintillators.

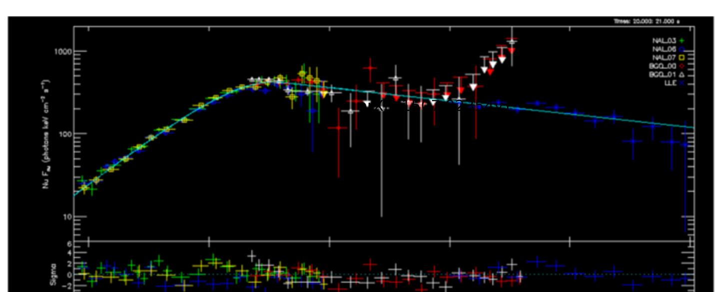
E-Astrogam aims to measure, alongside with the e+/e− pair production, Compton scattering interactions of the incident photons. In the first case, a photon is simply converted into secondary particles within the Tracker, then the Calorimeter measure the energy deposit and allows to complete the trajectory and energy reconstruction of the incident photon.

Compton events are a bit more tricky to detect : as is shown in the picture, if only the scattering of the photon is detected in the Tracker, the set of possible incident directions is a ring in the sky. Therefore the **detection of the recoil electron** has to be carried out in order to obtain a smallerring and optimize the event reconstruction.

GRB MODELING AND SIMULATION



Here we show an example of a lightcurve and a spectrum obtained for the prompt emission of GRB131108: the former is obtained using one NaI detector and the latter uses data from both GBM and LAT.

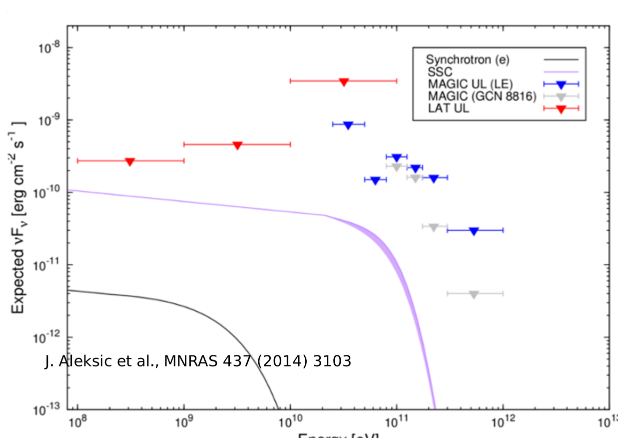


The GRB prompt emission spectrum is usually fitted using the **Band model**. This empirical function is characterized by two power-laws smoothly connected at a peak energy.

$$N(E) = \begin{cases} E^{\alpha} \exp\left(-\frac{E}{E_0}\right), & \text{if } E \leq (\alpha-\beta)E_0 \\ [(\alpha-\beta)\,E_0]^{(\alpha-\beta)}\, E^{\beta} \exp(\beta-\alpha), & \text{if } E > (\alpha-\beta)E_0 \end{cases}$$

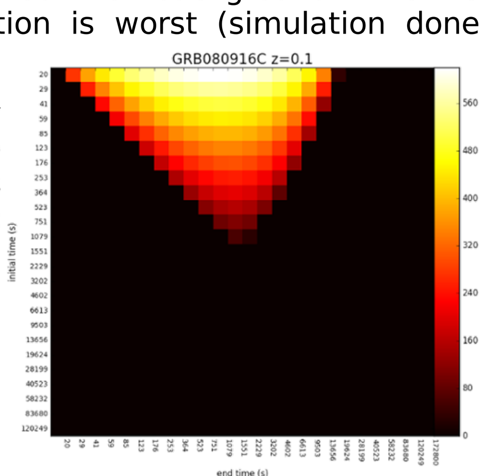
Power-laws are used because the **synchrotron** and **inverse Compton** processes have spectra with this shape.

This figure shows the upper limits set by MAGIC and LAT for the afterglow emission of GRB090102, compared with the modelling of the two main leptonic processes thought to be the origin of High Energy (HE; E<100 GeV) and Very High Energy (VHE; E>100 GeV) emission of GRBs.



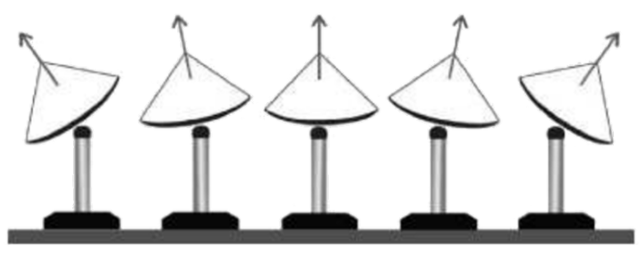
In order to observe a GRB, a fast repoint time from the alert is mandatory, due to the fast decreasing of the flux with time. Too long observations increase the amount of background which is included and therefore the detection is worst (simulation done with ctools and Gammalib).

High redshift GRBs, are less likely to be seen at VHE due to the higher absorption of VHE photons interacting with the **Extragalactic Background Light**.



Observation modes

We are also studying the **divergent pointing** mode for CTA, which is a different observing mode with respect to to normal parallel one.

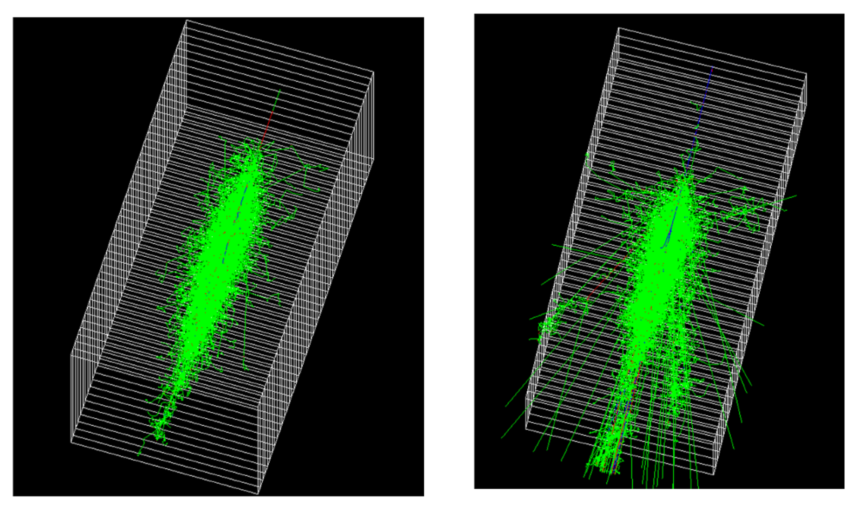


SHOWER SIMULATIONS

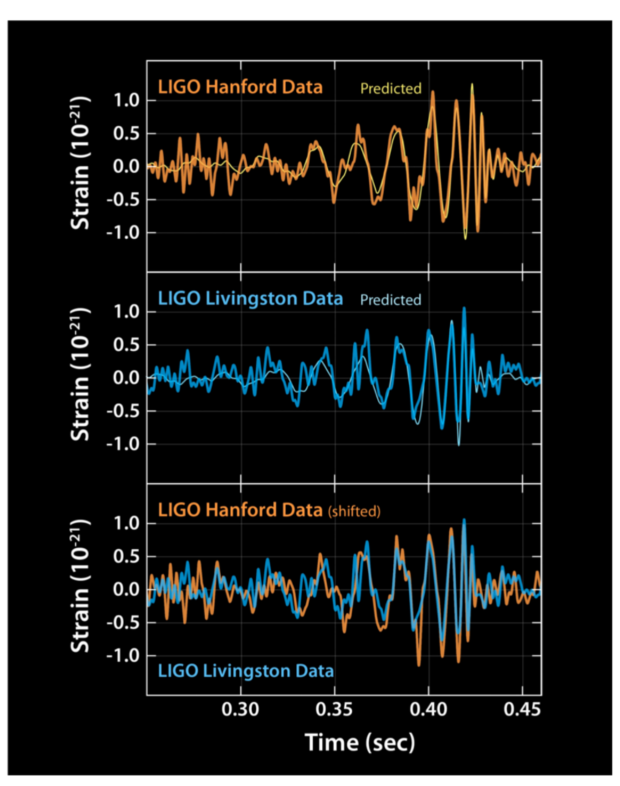
A very important task in studying the performance of a IACT telescope is the creation of Instrument Response Function, by means of Monte Carlo simulation of gamma-rays and protons interacting with the atmosphere.

Developement of atmospheric shower (Geant4)

1 TeV photon **1 TeV proton**



FUTURE PERSPECTIVES

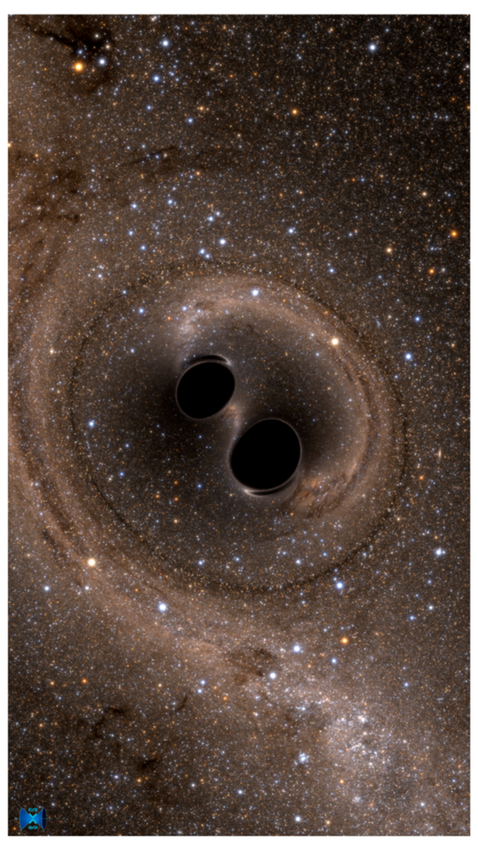


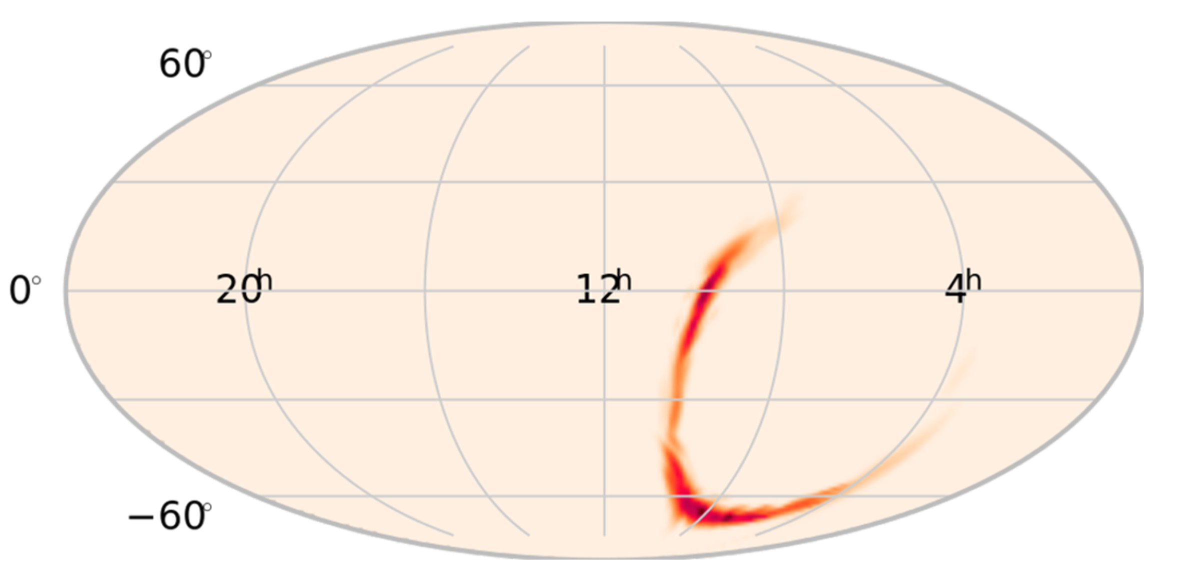
After 100 years from Einstein's formulation of **General Relativity** theory, the first O1 LIGO-Virgo science run provided the first direct detection of a **Gravitational Wave** (GW) signal from a black hole-black hole system on 14th September 2015. More and more discoveries are expected when both LIGO and Virgo will reach their design sensitivity for the next science run in 2016.

This exciting discovery opened a new window in astrophysics and astroparticle physics, leading to a better understanding of our Universe.

An important piece is the study of these transients events in both GW and electromagnetic channels. Among the ground-based electromagnetic facilities, the MAGIC collaboration is preparing follow-up programs for GW alerts in the VHE band. In particular, the systems producing gravitational waves (two black holes, two neutron stars or one neutron stars and one black hole) are also thought to be the cause of the short class of GRBs.

In this framework, the linked GW-EM studies will help answering one of the many open questions about gamma-ray burts, that is the determination of the progenitors causing these brief flashes of very energetic gamma radiation.





This is the localization skymap, provided by the LIGO/Virgo collaboration, for the gravitational wave event of the 14th of September, 2015.

The skymap can be used by electromagnetic observatories to do follow-ups of GW events searching for a coincidence with other sources like GRBs.

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