Gamma-ray burst observations at very high energy with MAGIC and the LSTs

Léa Jouvin

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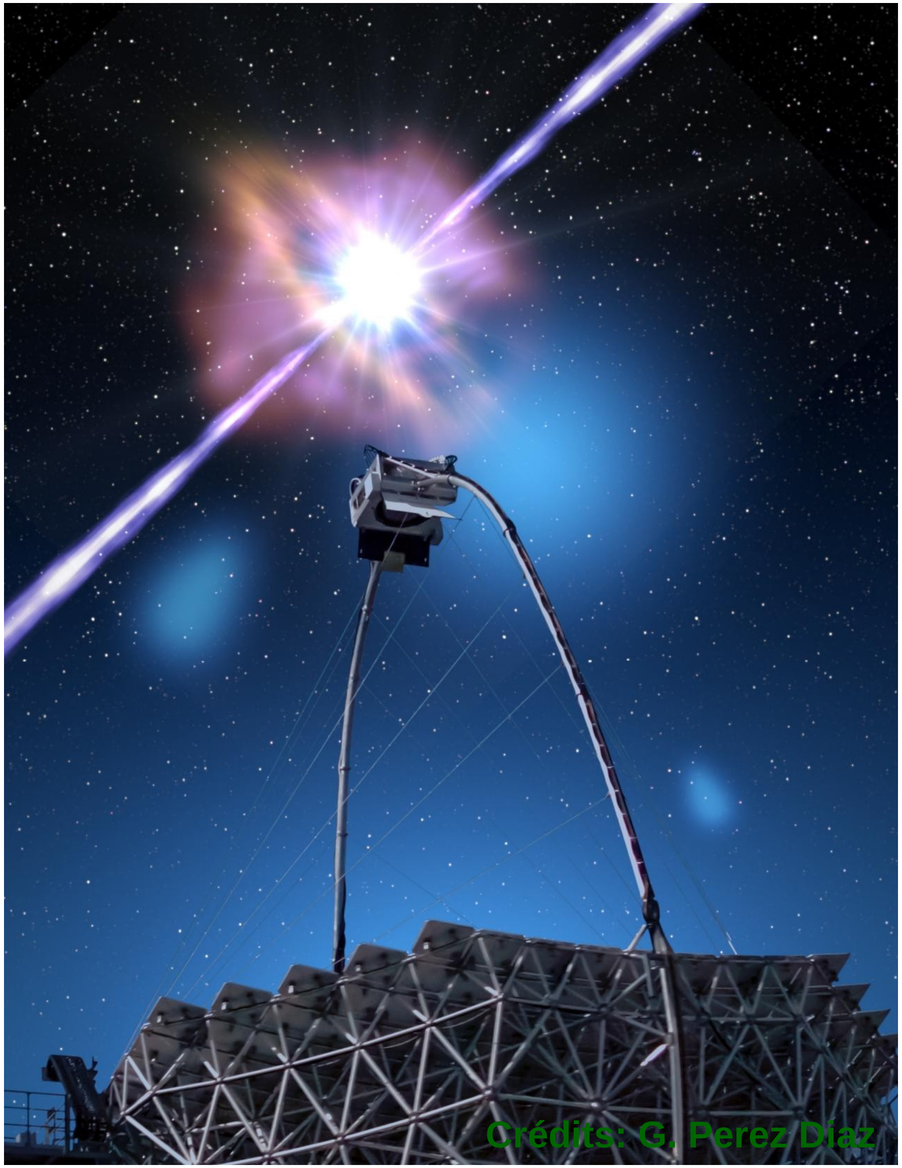
Gamma-ray burst (GRB)

- Intense flash in the keV-MeV band followed by a fading and long-lasting emission



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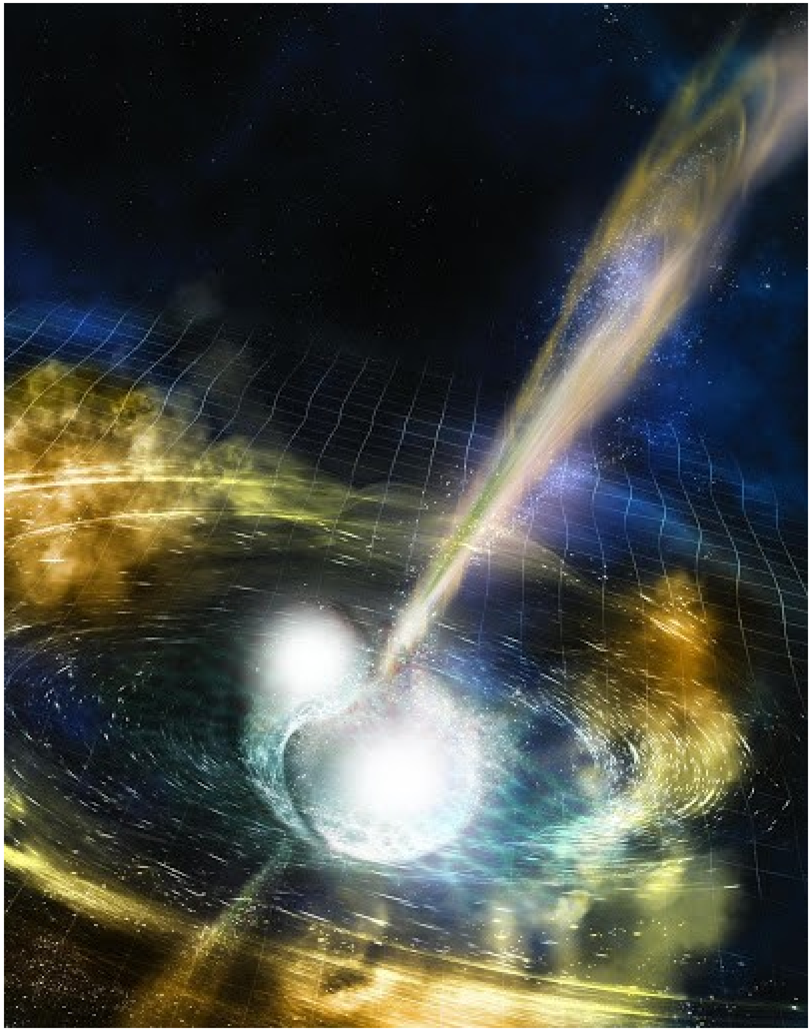

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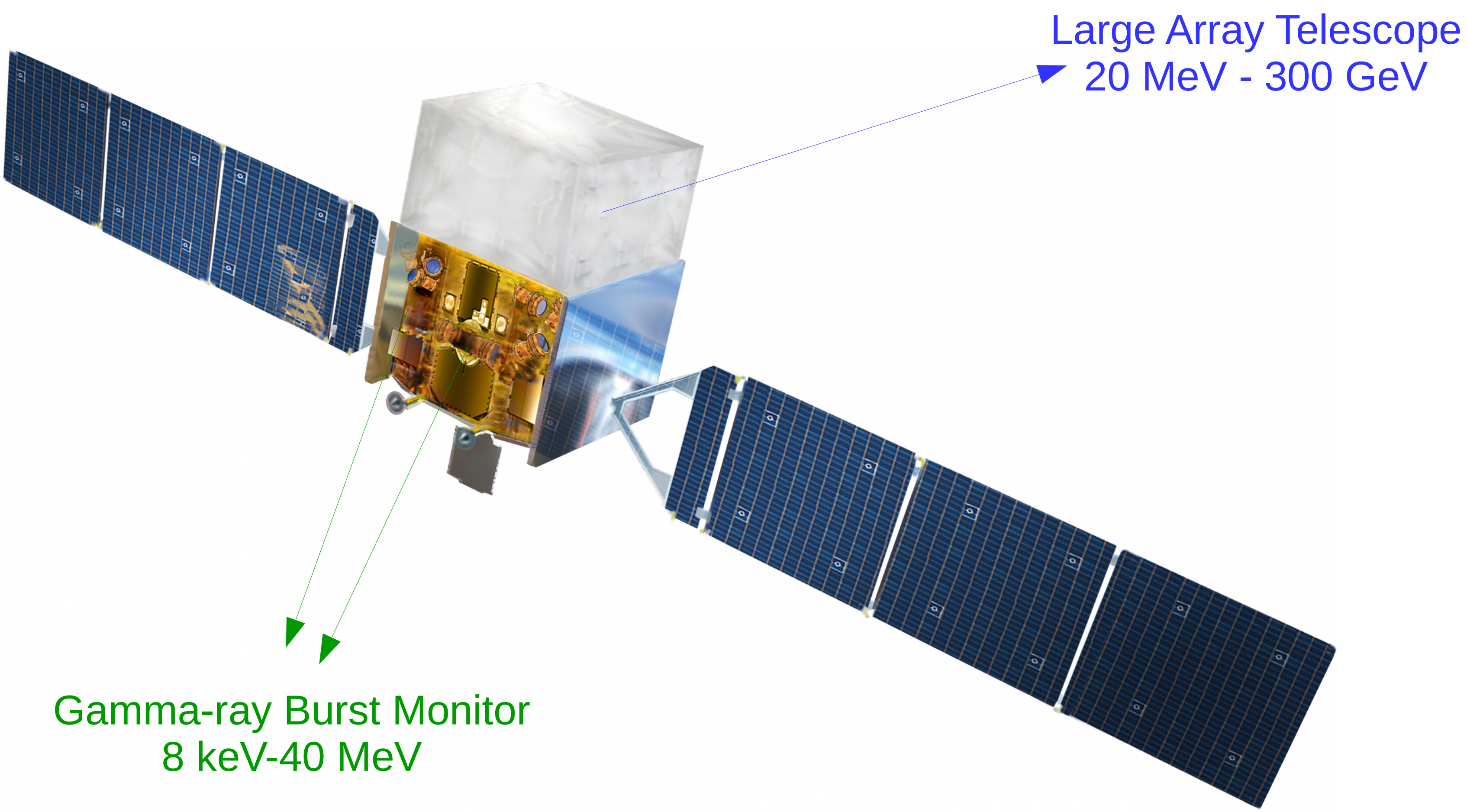
- To higher energy: Fermi launched in 2008



Outlines

1. Gamma-ray burst properties

2. Observation of GRB190114C by the MAGIC telescopes

3. Future observations with the Large Size Telescope of CTA

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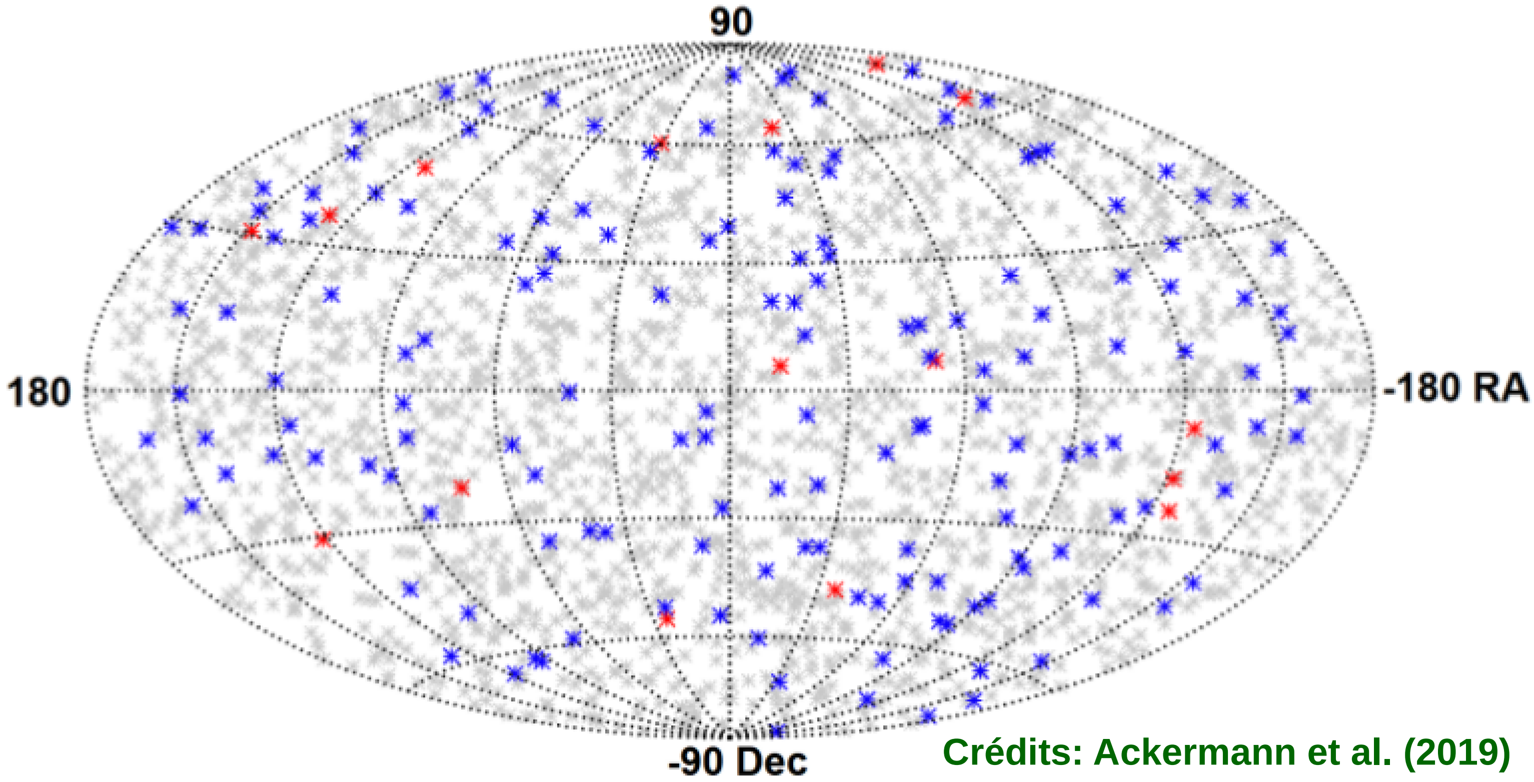

Crédits: Ackermann et al. (2019)

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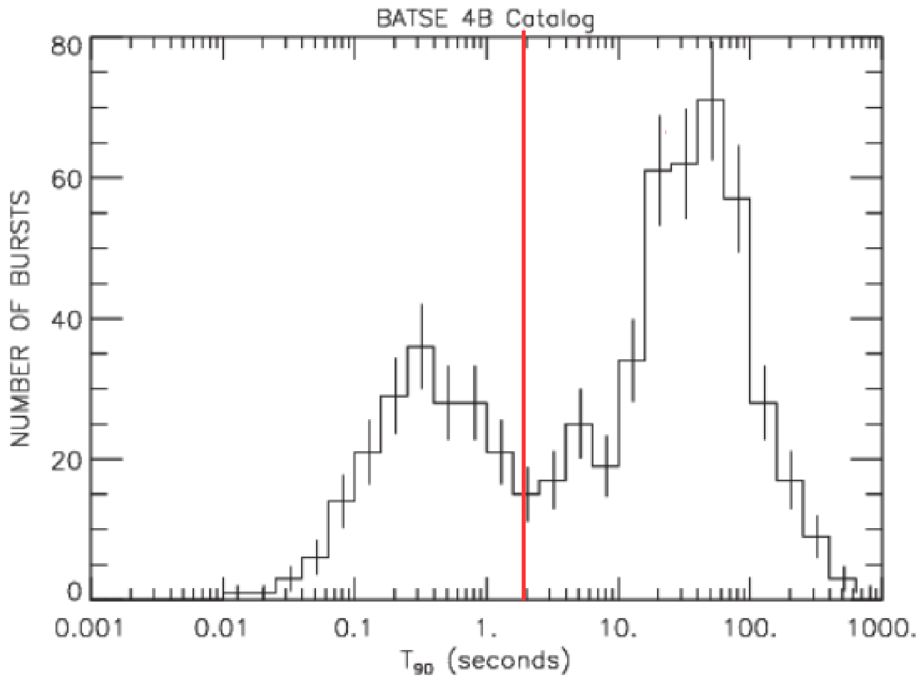

4^{th} catalog: 1637 bursts

Crédits: Meegan et al., 1996

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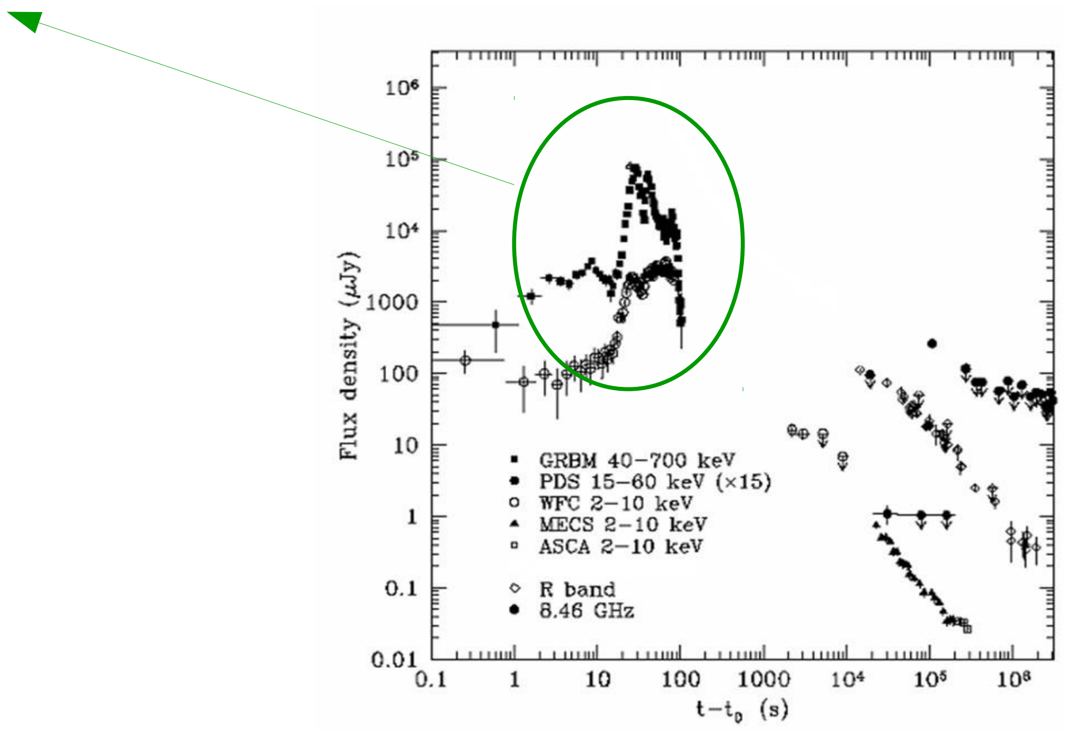

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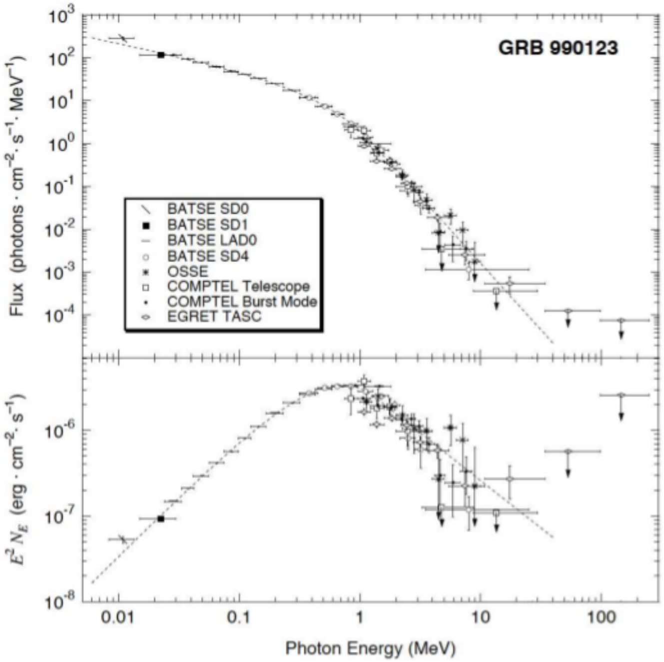

Crédits: Briggs et al., 1996

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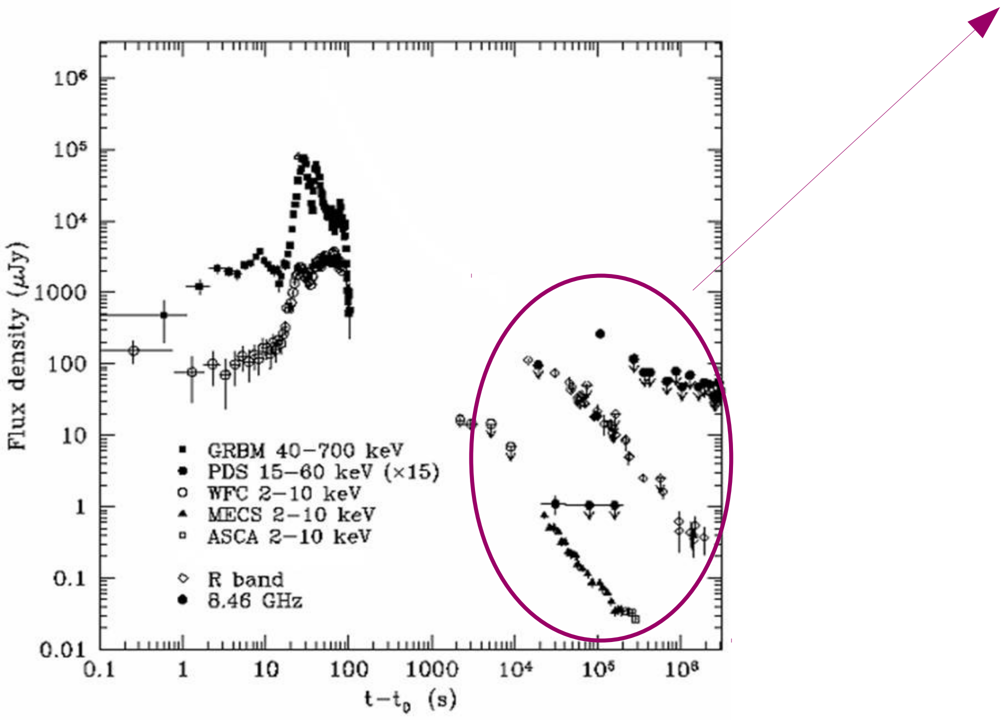

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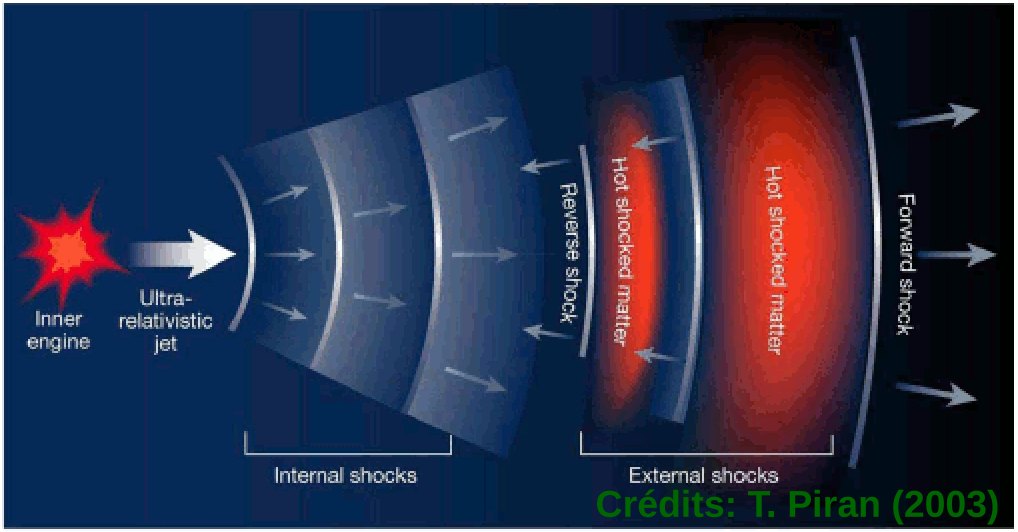

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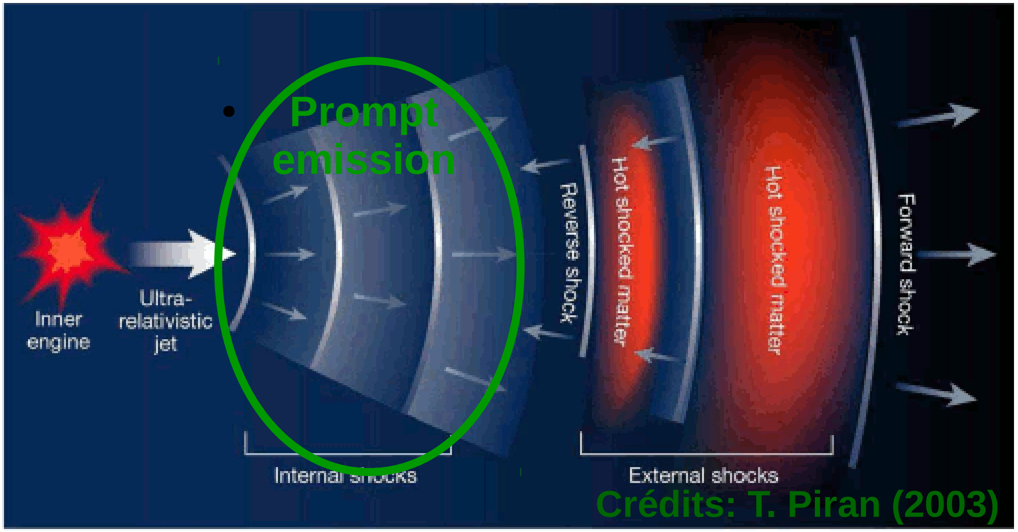

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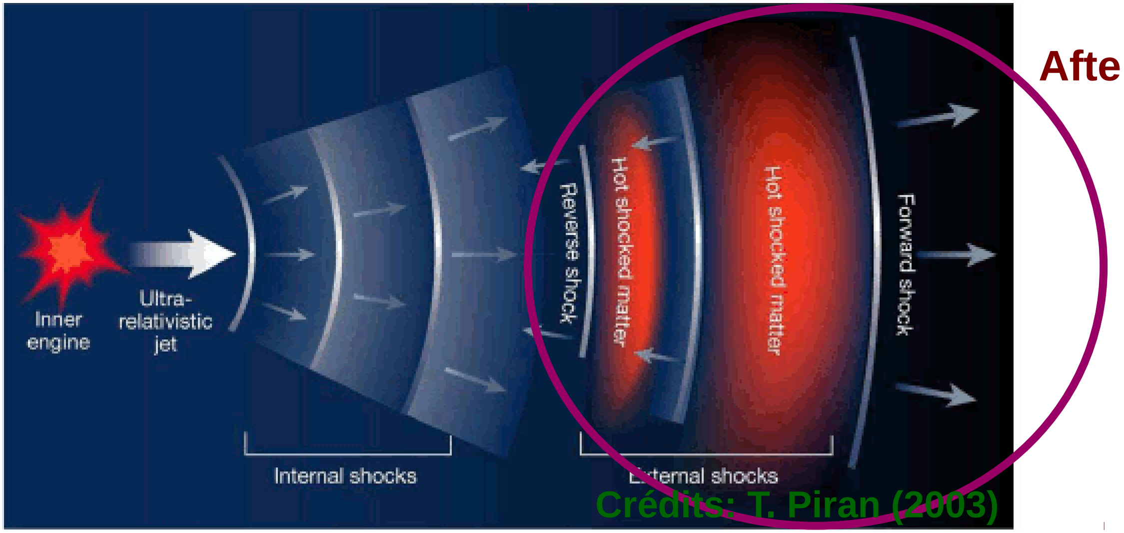

Afterglow

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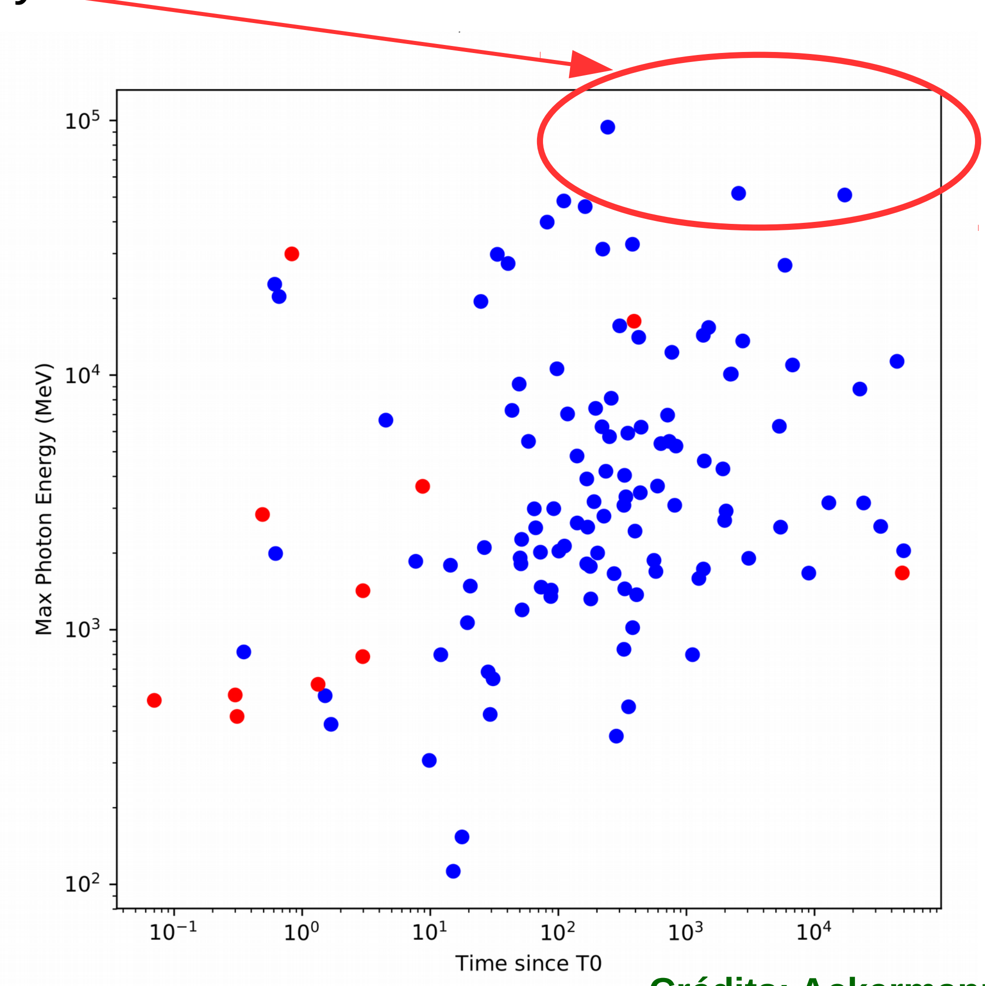
Potential of detection by Imaging Air atmospheric telescope (IACT)

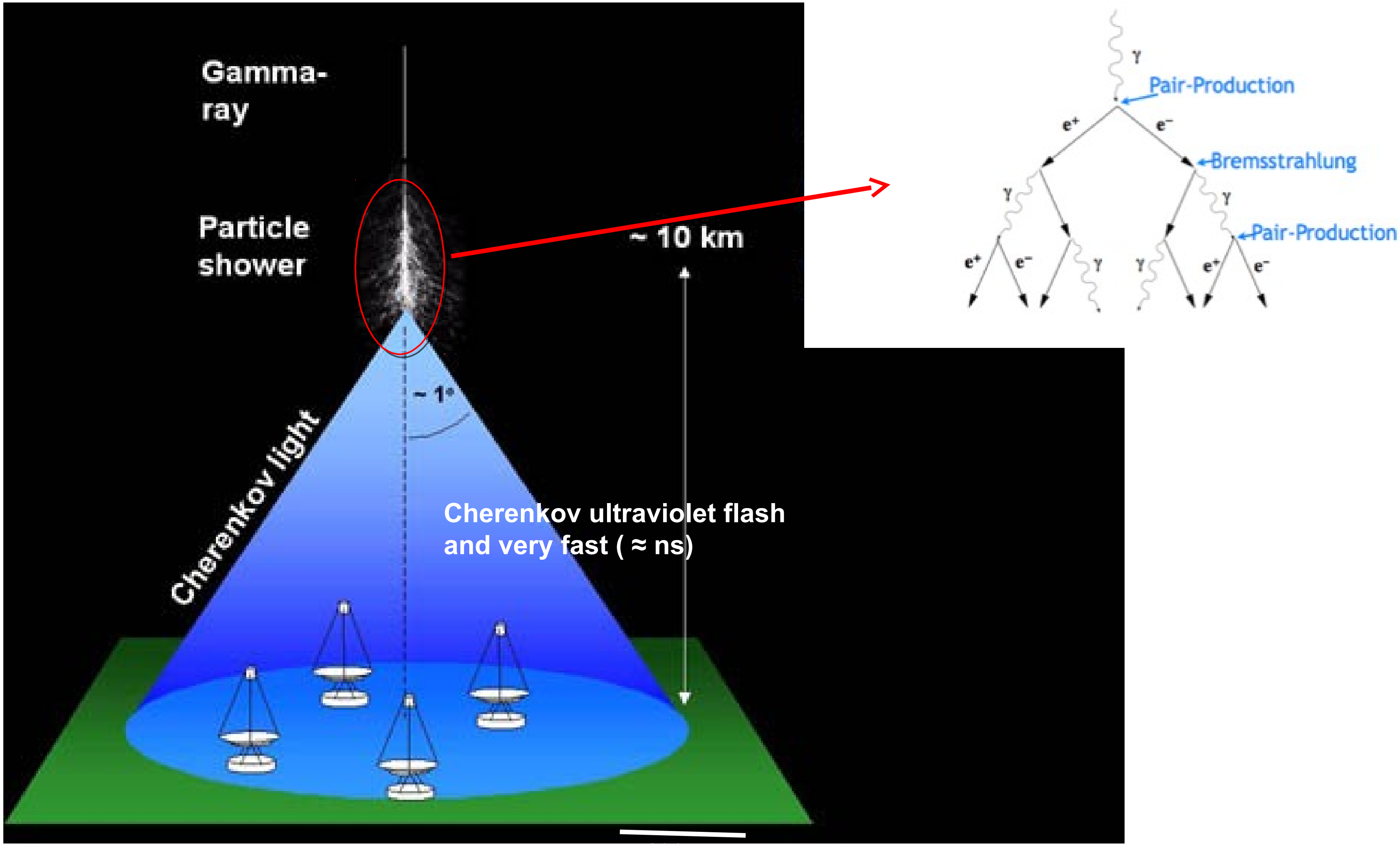
→ Fermi-LAT detects ~ 19 GRBs by year

→ only 3 of these GRBs could have been detected by an IACT



Crédits: Ackermann et al. (2019)

Particles showers and Cherenkov emission



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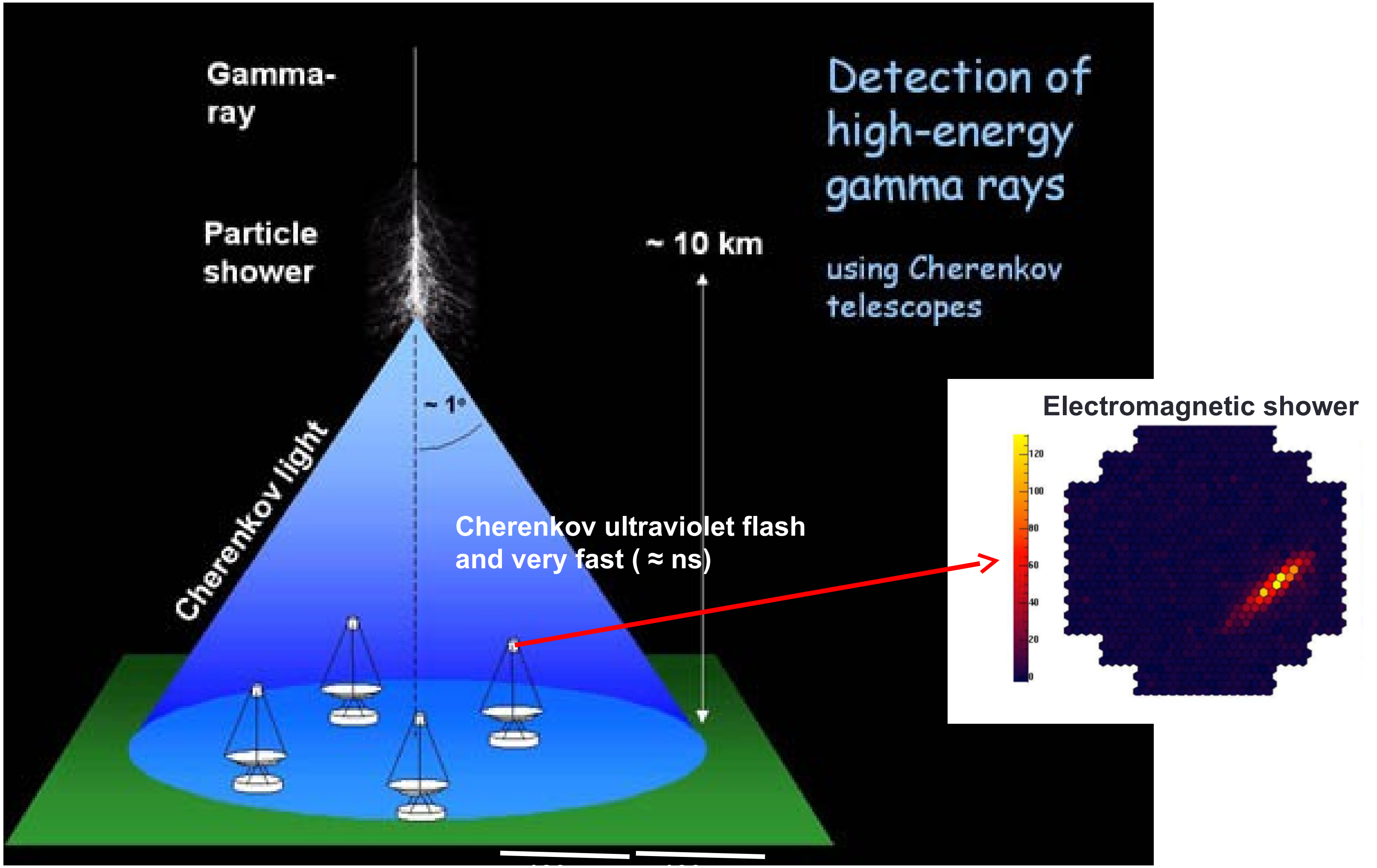
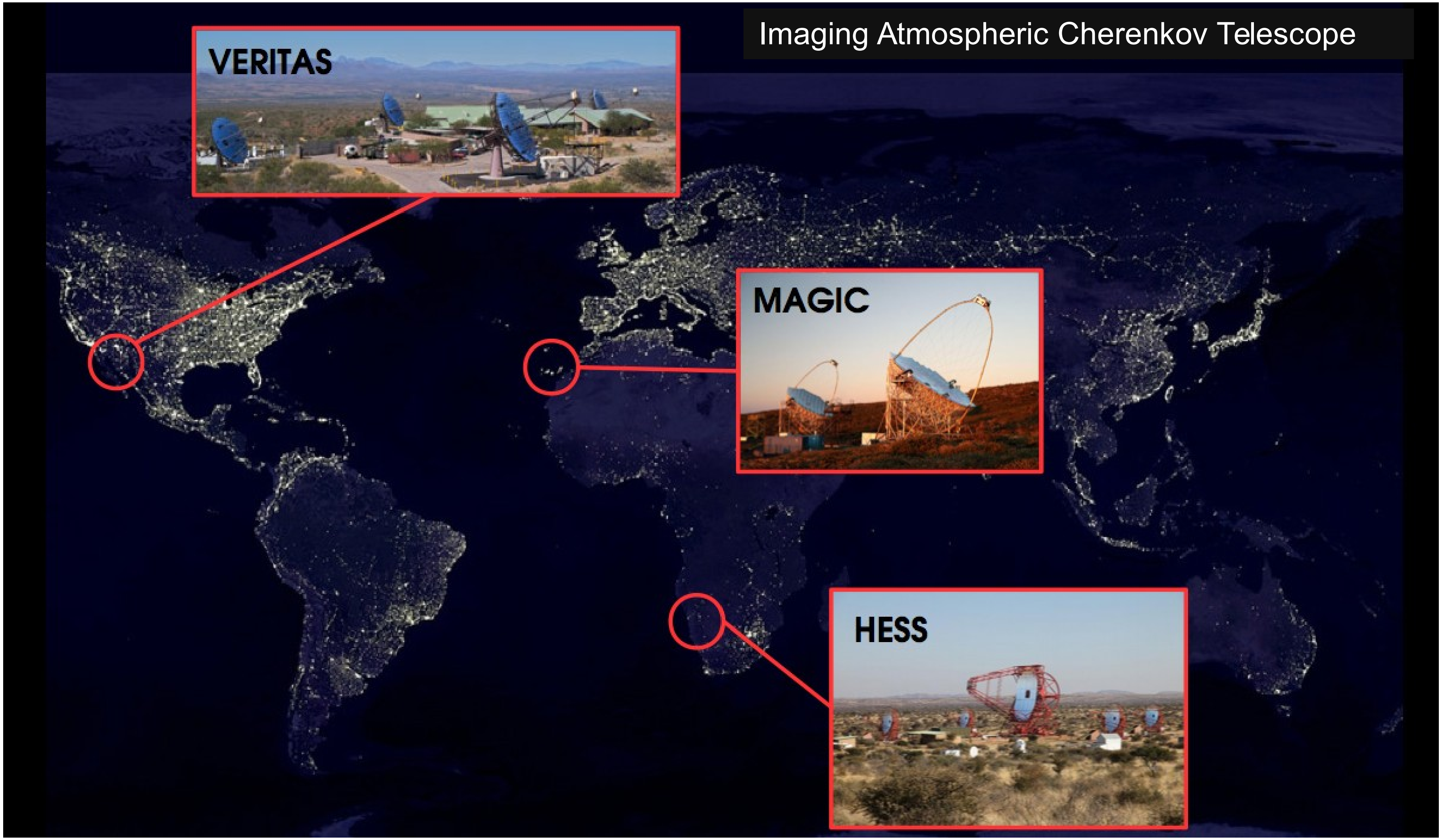


Very high energy γ astronomy (E > 30 GeV)



The MAGIC telescopes

- Two IACTs located in the Observatory Roque del Muchachos at La Palma Islands
- Altitude: ~ 2200 m
- Detects γ-ray: from ~ 30 GeV to ~ 30 TeV
- Field of view: ~ 3.5°
- Angular resolution: ~ 0.1° (energy dependent)

→ **Automated reaction to transient alerts (repositioning in less than one minute)**

How to catch a GRB ?

Improve the response time of the telescope to alerts

- Hardware (fast-movement)
- Software: acquisition ready as fast as possible

Increase duty cycle:

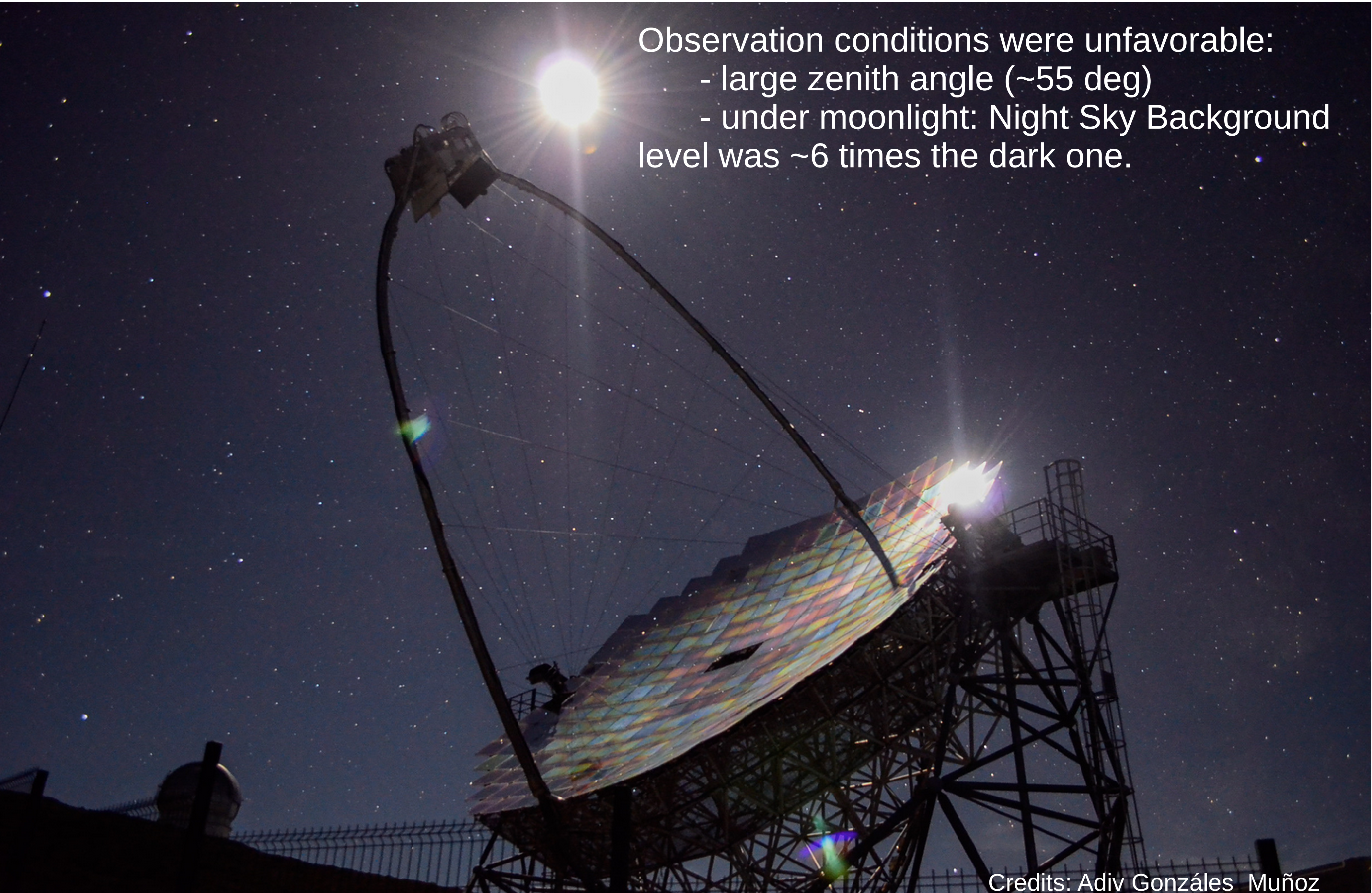
- Looser constraints on observability of the alert

  → led MAGIC to allow large zenith angle and moonlight observations

And after 15 years: 3 long GRBs detections in the past 1.5 years!

- GRB180720B by H.E.S.S.: T_0 + 10h
- GRB190114C by MAGIC: T_0 + 62 s
- GRB190829A by H.E.S.S.: T_0 + 4h

MAGIC observation of GRB190114C



Observation conditions were unfavorable:

- large zenith angle (~55 deg)
- under moonlight: Night Sky Background level was ~6 times the dark one.

Credits: Adiv Gonzáles Muñoz

Observation by MAGIC

At T0 = 20:57:03 UT Swift/BAT and Fermi/GBM triggered on GRB190114C

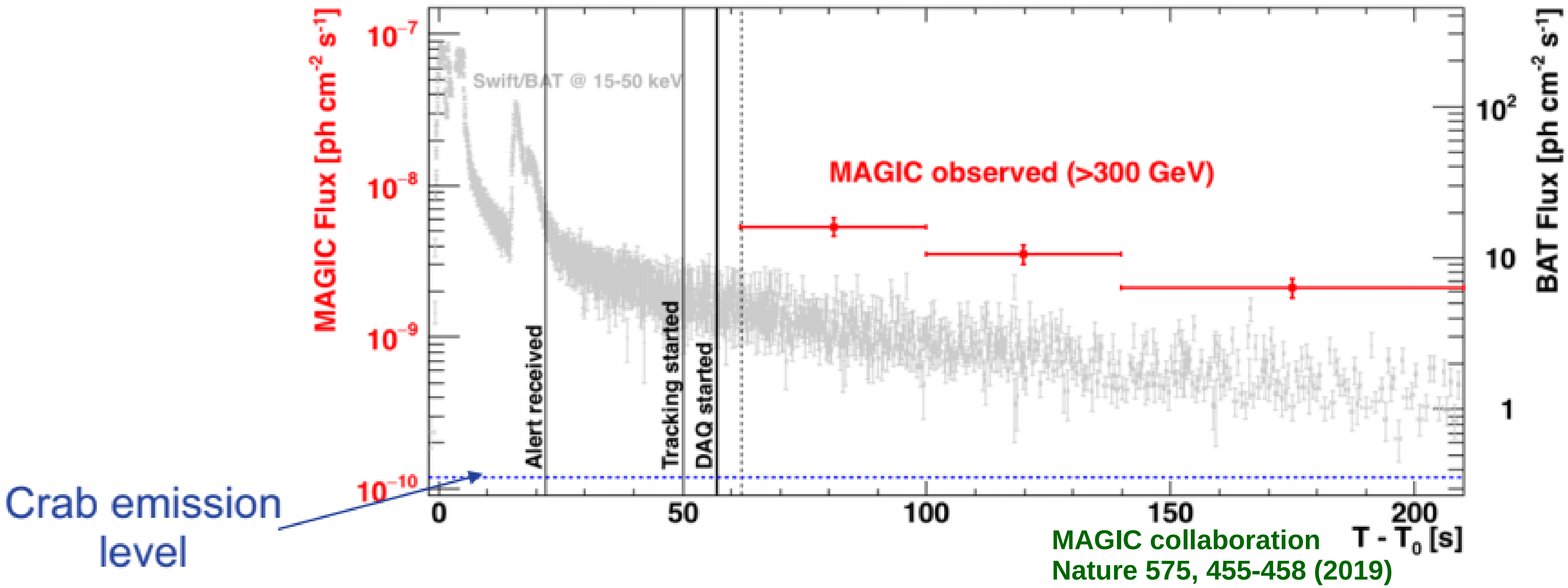
T0+22s MAGIC received the alert

T0+50s MAGIC started tracking

T0+57s MAGIC started data acquisition (35s after the alert)

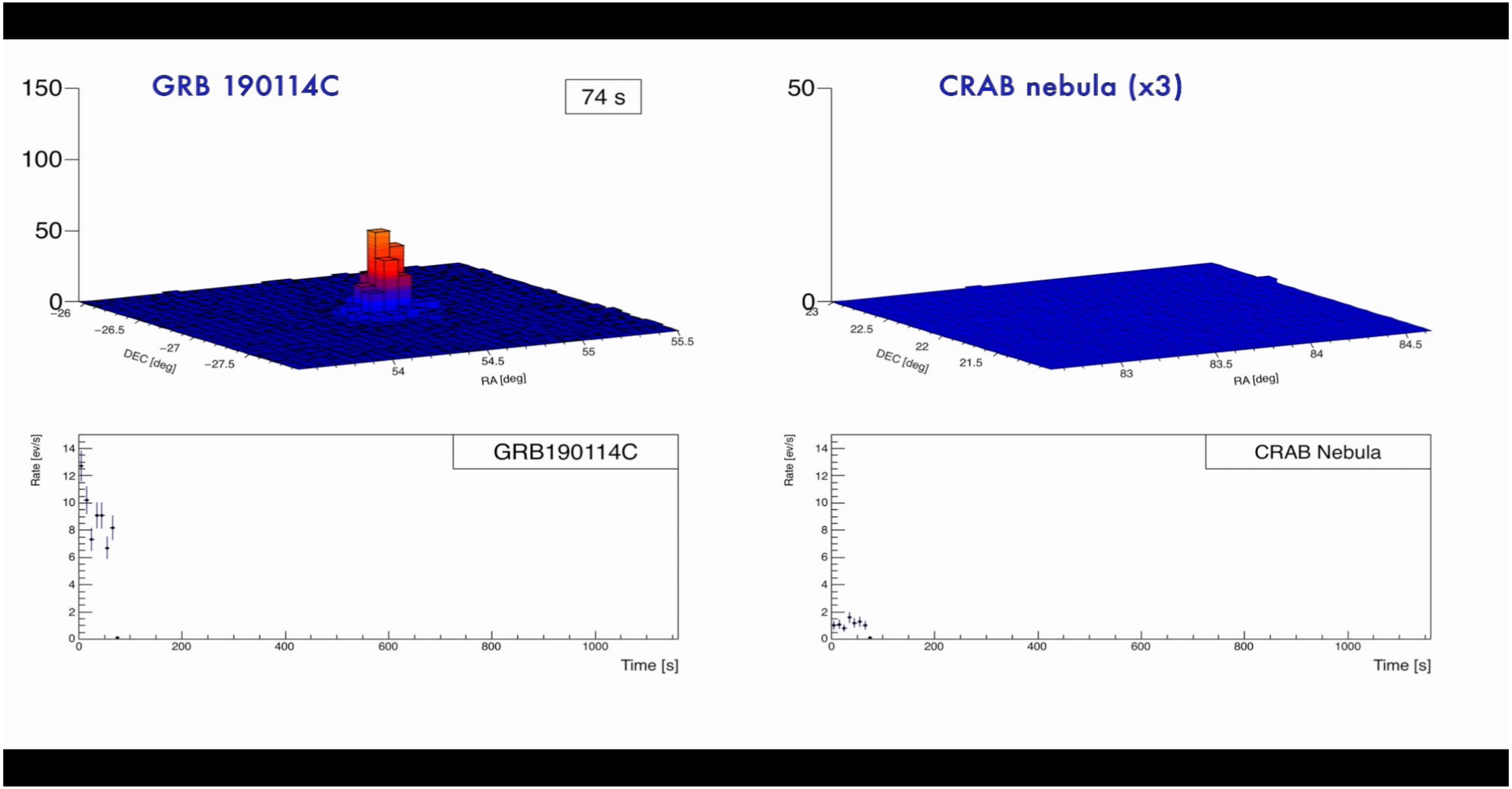
T0+62s MAGIC data acquisition stabilized

→ **Long GRB at redshift z = 0.4245 ± 0.0005 (A. J. Castro-Tirado GCN 23708)**



First 30 seconds: 100 * Crab Nebula (> 0.3 TeV)

GRB190114C detection by MAGIC



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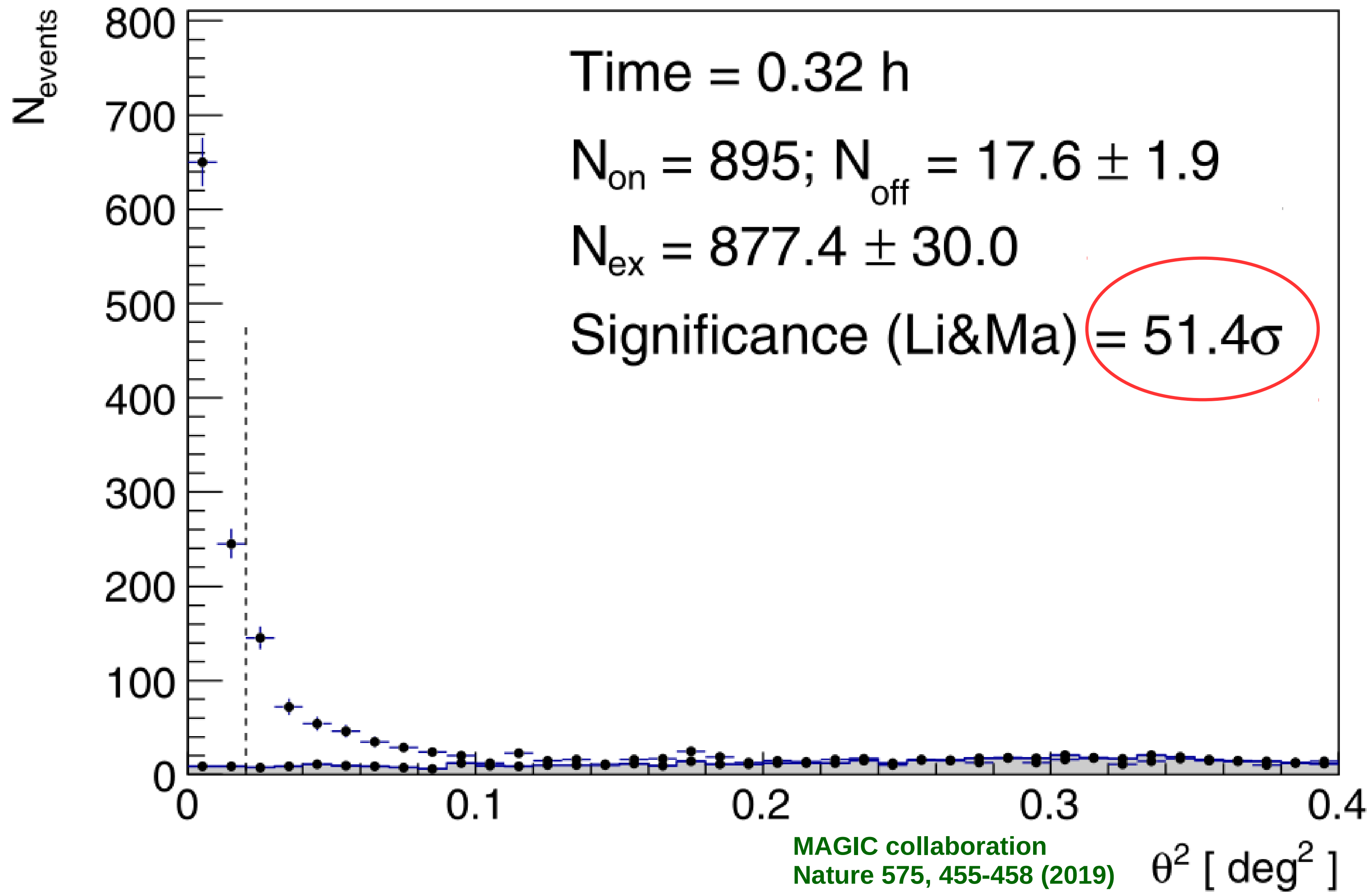
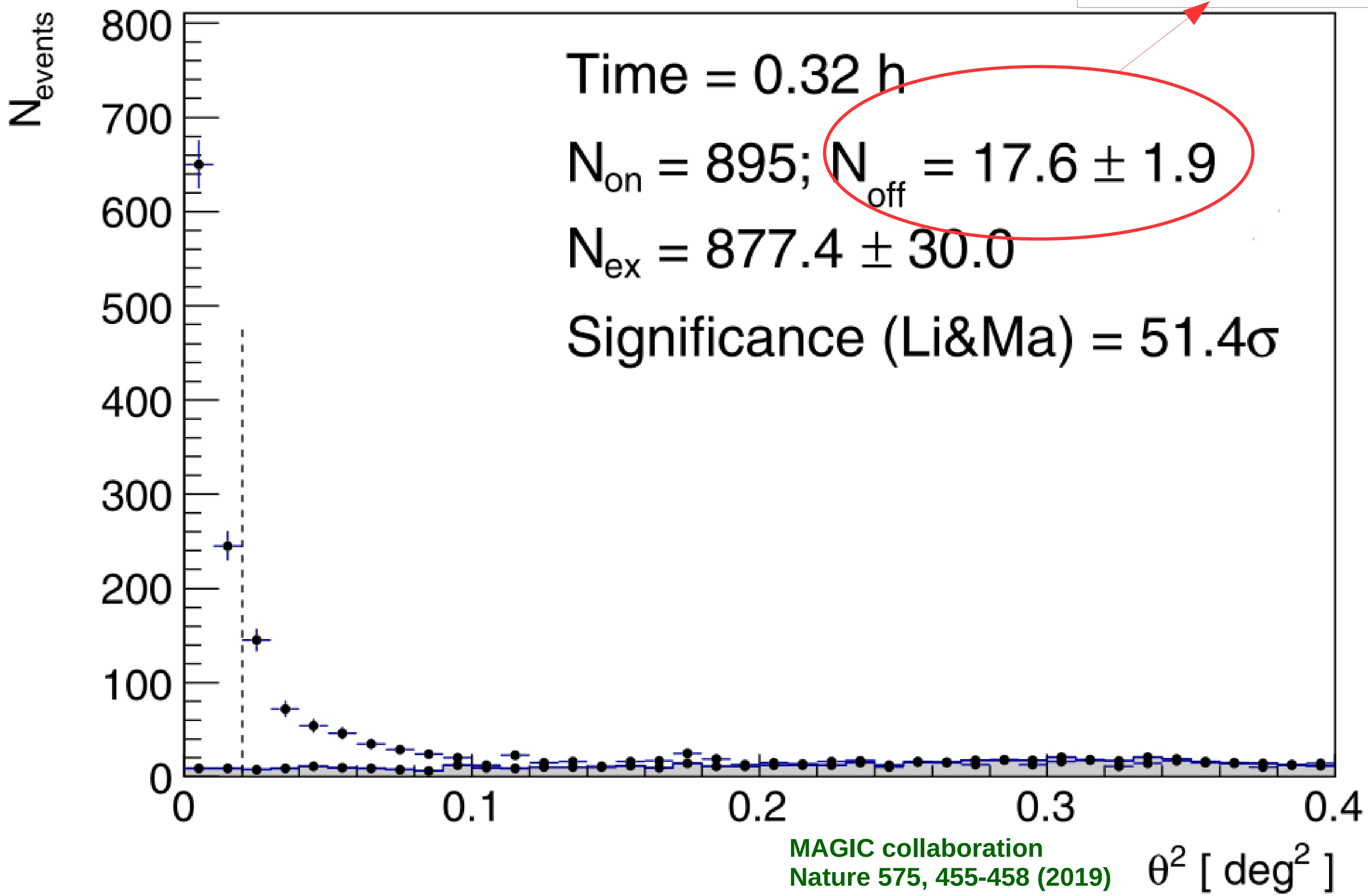


MAGIC collaboration
Nature 575, 455-458 (2019)

GRB190114C detection by MAGIC

Very low background
→ almost background free



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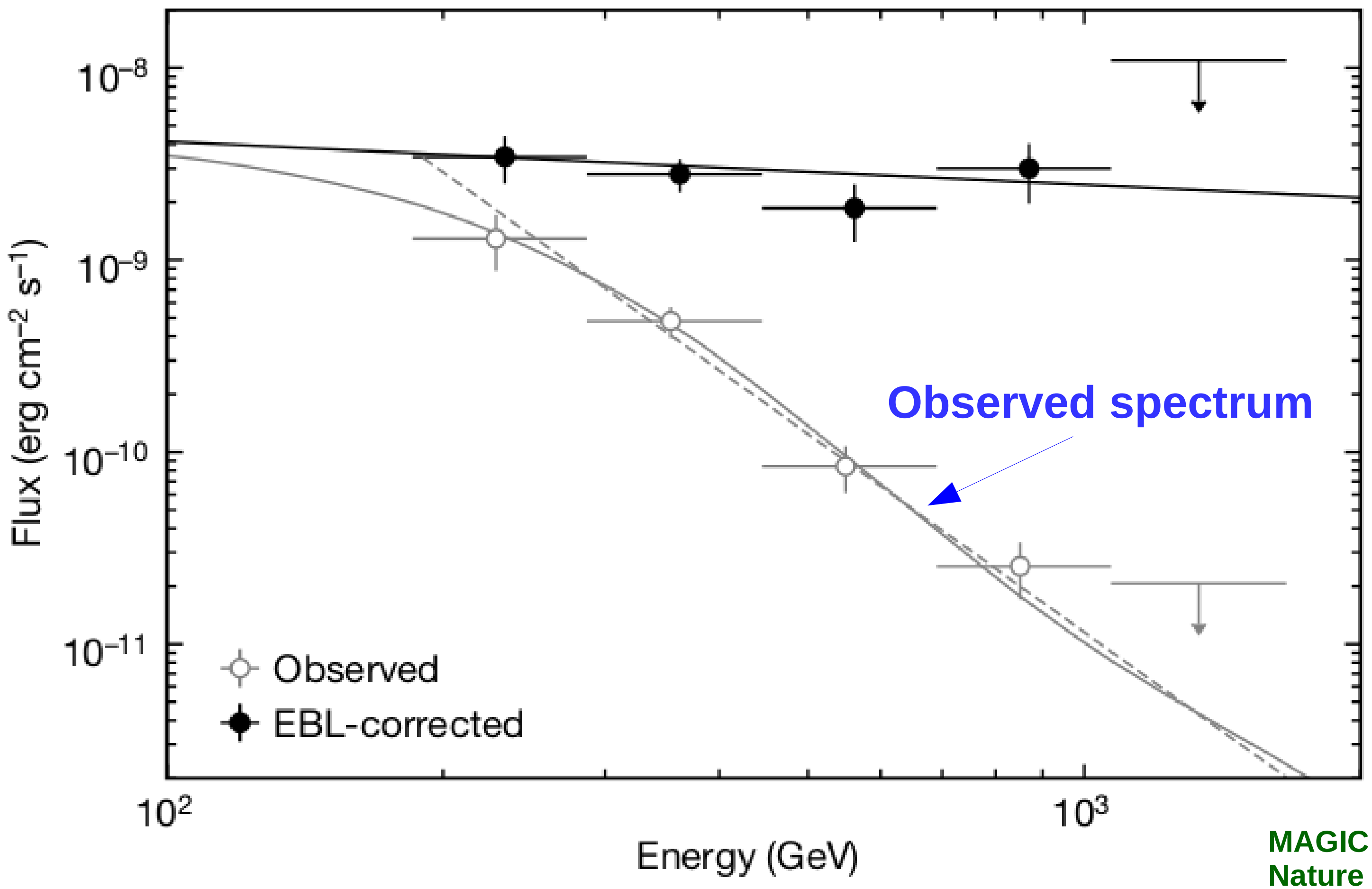
GRB190114C spectrum

Spectrum extracted on ~ first 40 minutes of observation



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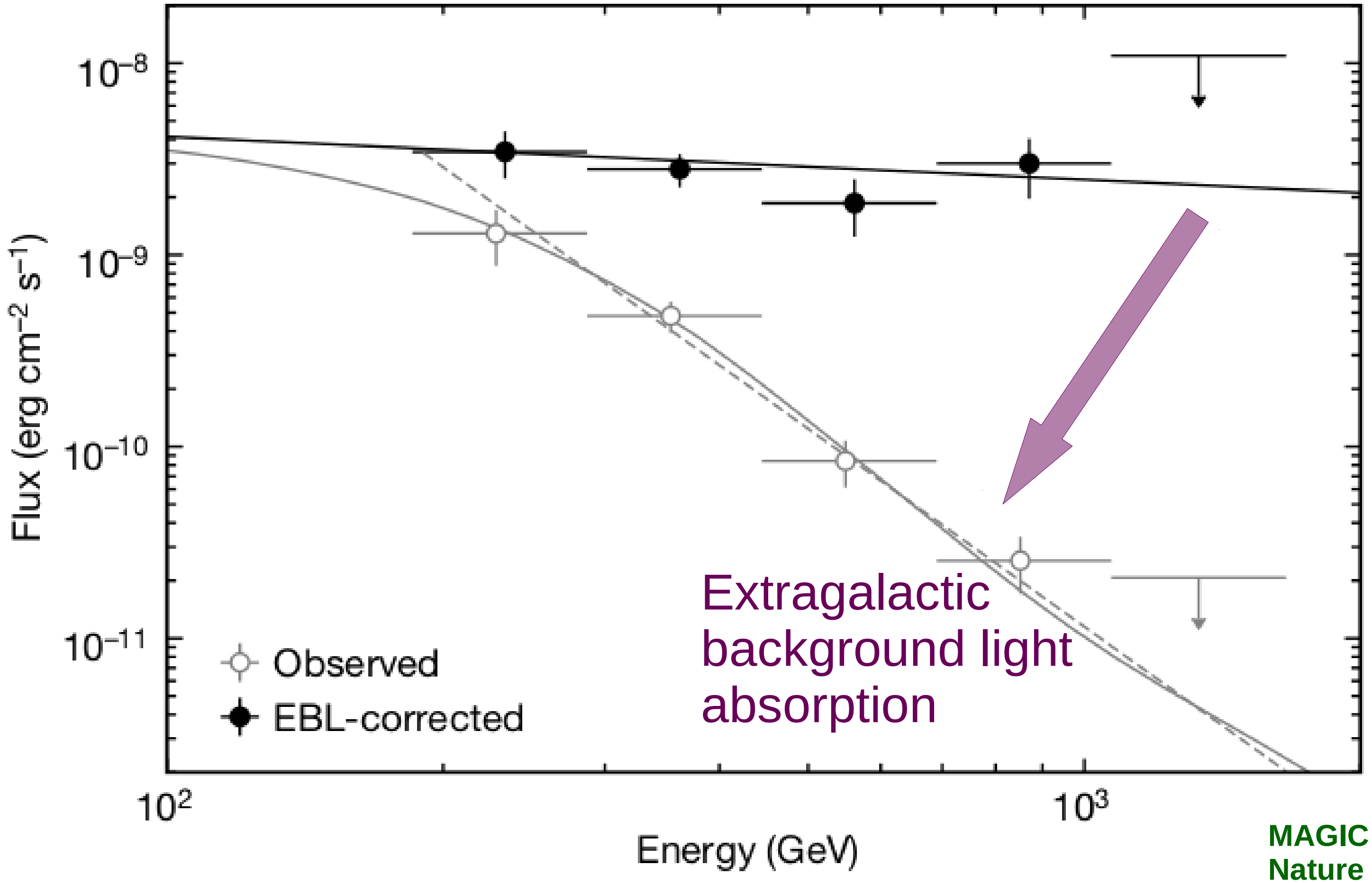

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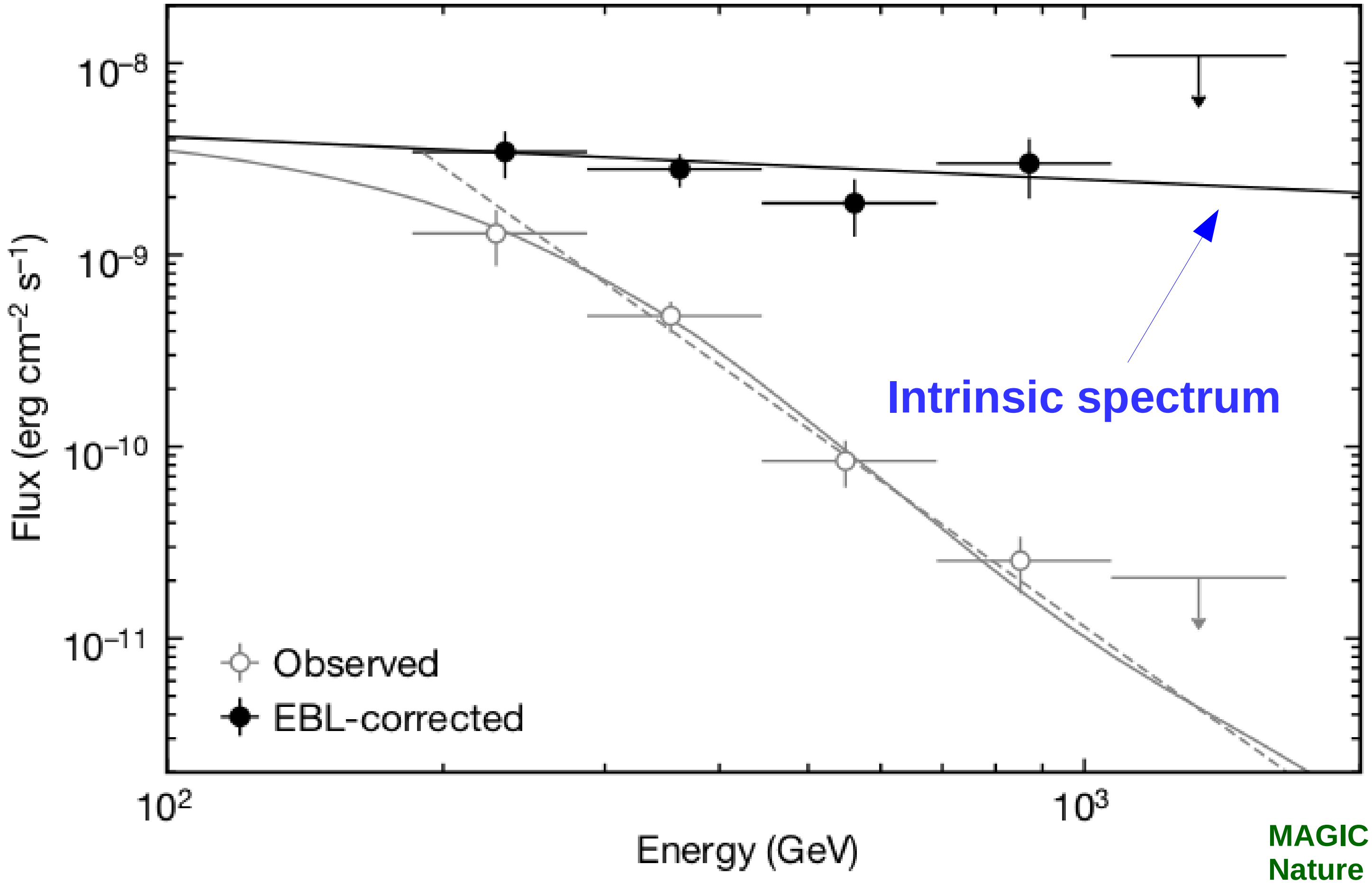


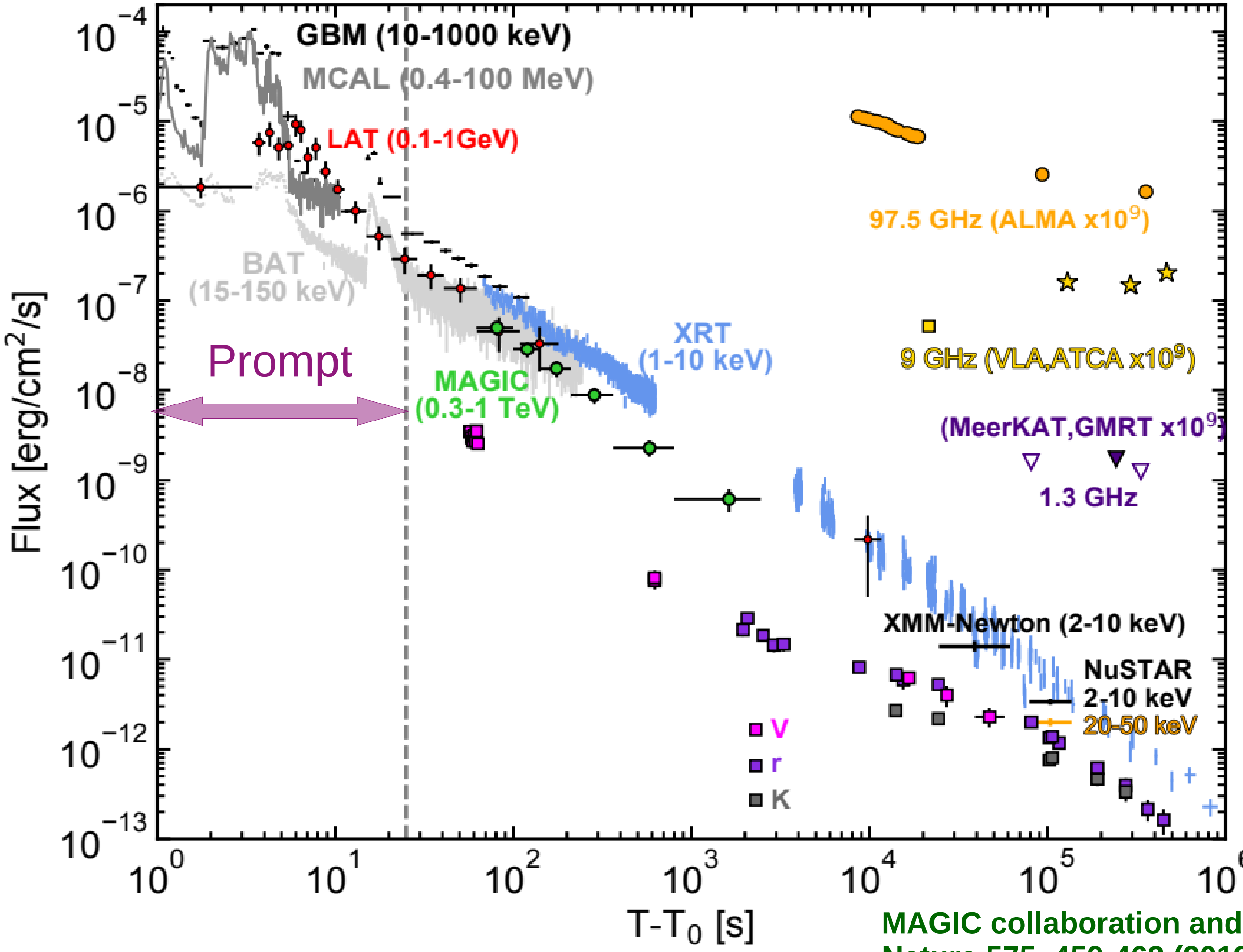
MAGIC collaboration
Nature 575, 455-458 (2019)

→ **Energy flux emitted at sub TeV about half of the one emitted in X-ray on the first 40 minutes**

Multi-wavelength temporal profile

→ The prompt phase lasts for ~12 sec

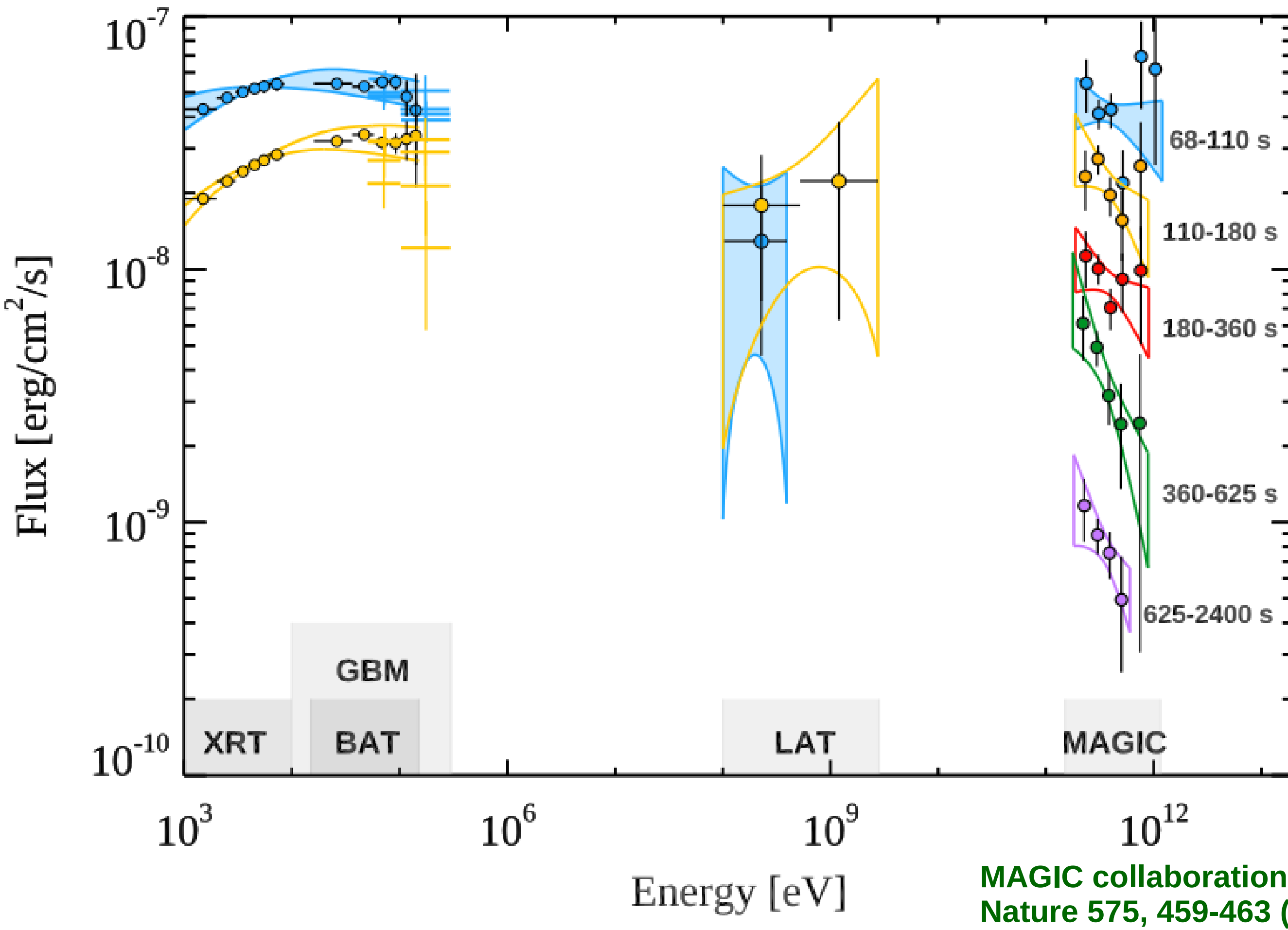
→ MAGIC starts its observations in the so-called **early afterglow phase**



MAGIC collaboration and others, Nature 575, 459-463 (2019)

Spectral energy distribution

Broadband spectra in the time interval 1-40 minutes



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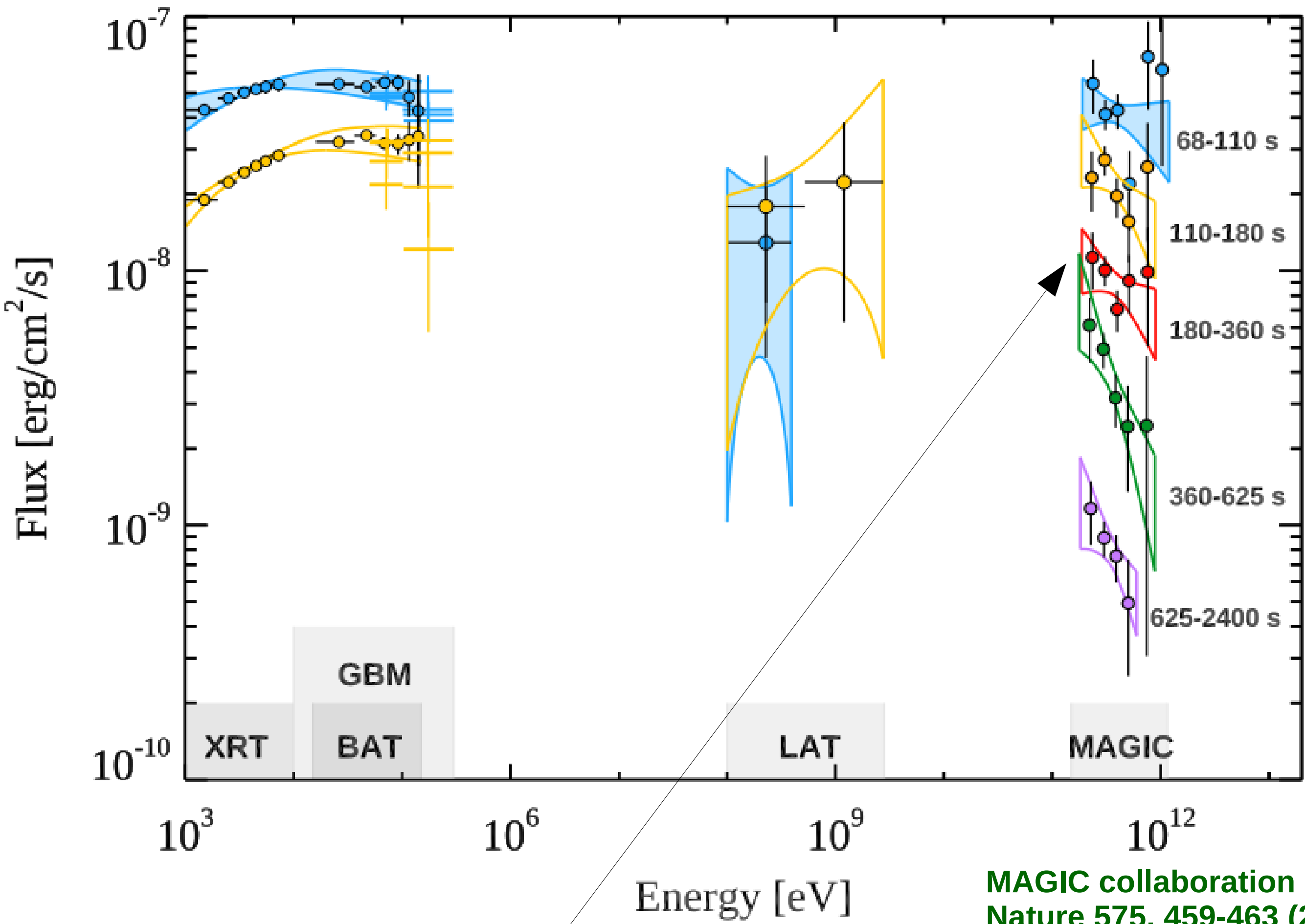

MAGIC collaboration and others,
Nature 575, 459-463 (2019)

New TeV emission:

→ not a simple extension of the known afterglow synchrotron emission

→ same forward shock, but different emission processes.

What comes next for GRB observation at VHE ?

- GRB: rather common both in energetics and in the derived physical parameters
- We could detect it because:
  - → we repointed fast
  - → we operated during moon light
  - → it was close
- First 30s: ~100 times higher than Crab Nebula (at 0.3 TeV).
- multi-wavelength follow-up: extra-component beyond synchrotron emission interpreted as a synchrotron self-Compton emission model

- **What perpectives?**
  - → IACT (H.E.S.S., MAGIC, VERITAS and **CTA**)
  - → SVOM
  - → HAWC/LHAASO
  - → ANTARES/KM3NET/Icecube
  - → LIGO/Virgo

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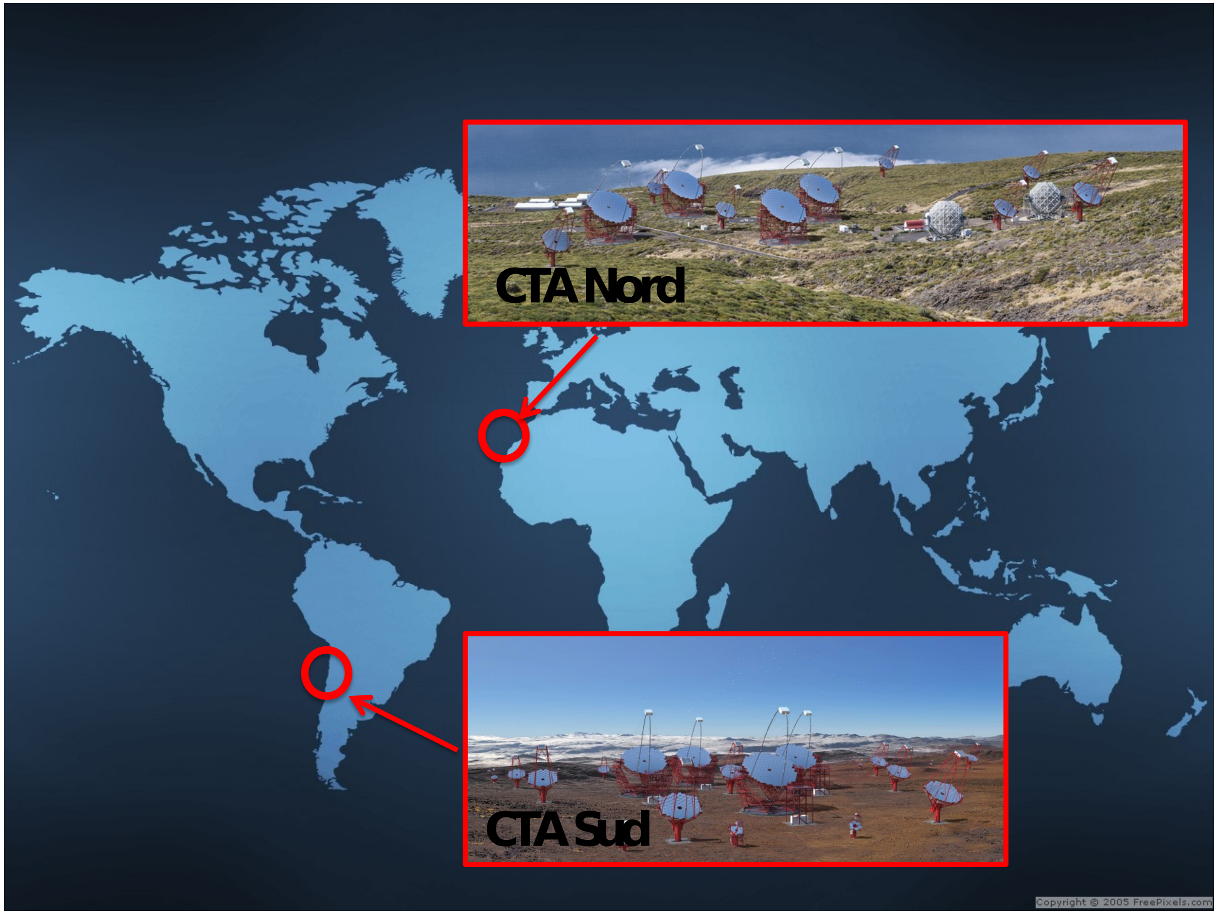
GRBs with the Large Size Telescopes (LSTs) of CTA

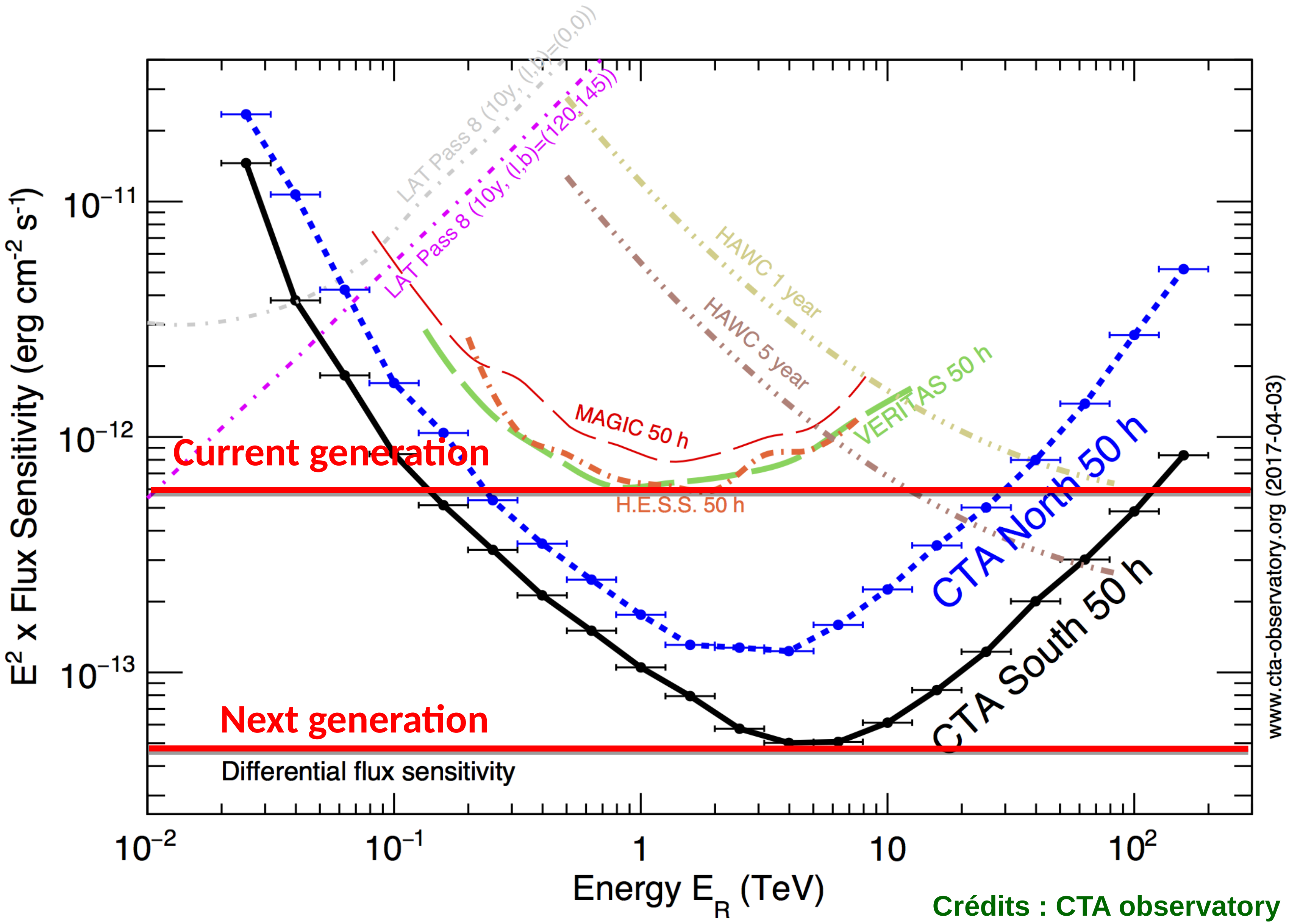
Crédits: T. Inada

The Cherenkov Telescope Array

- First public observatory in the history of Cherenkov Astronomy
- 3 telescope sizes: covers a larger range in energy and sensitivity
- Few GeV up to hundred of TeV.



The sensitivity



Crédits : CTA observatory

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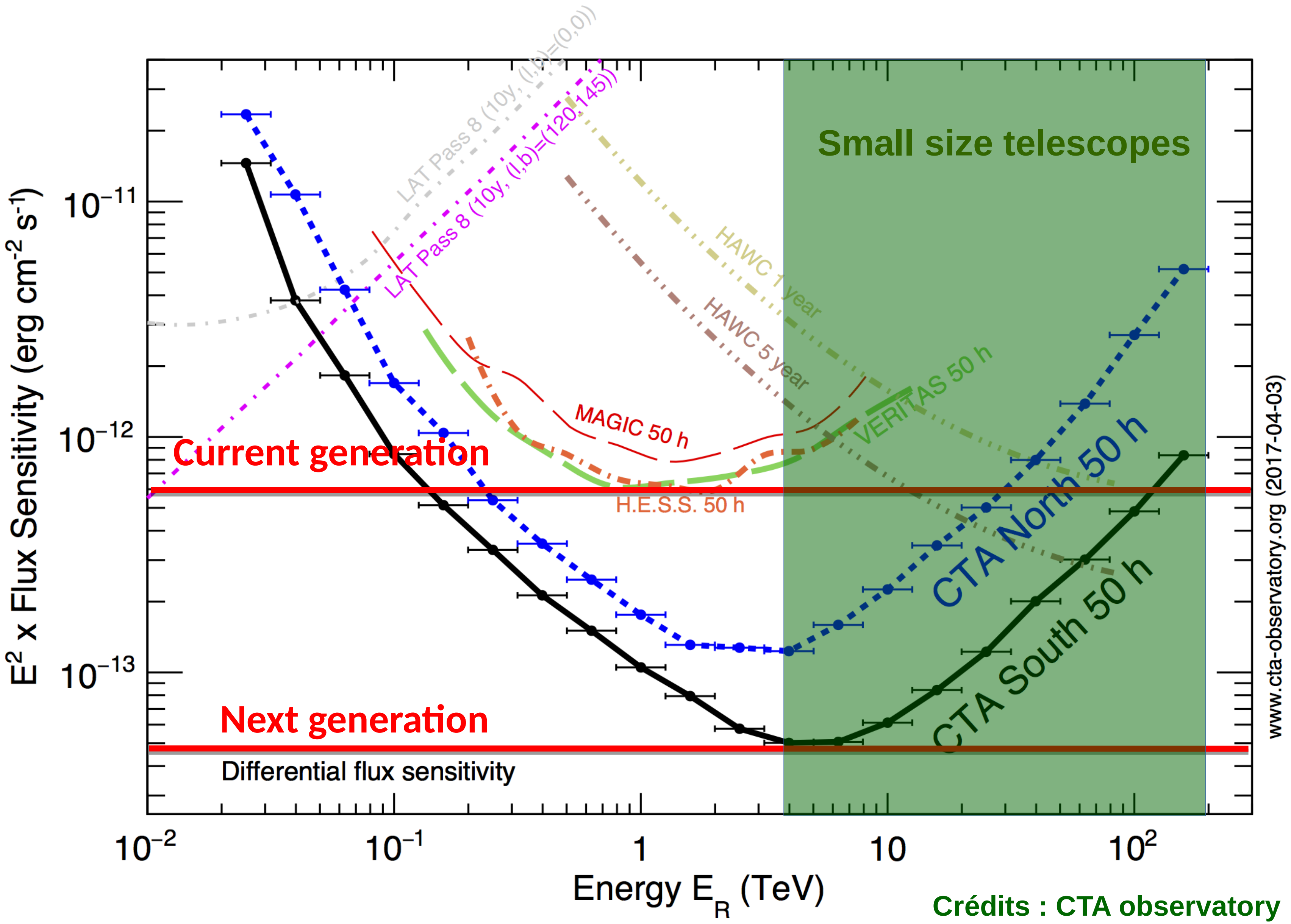

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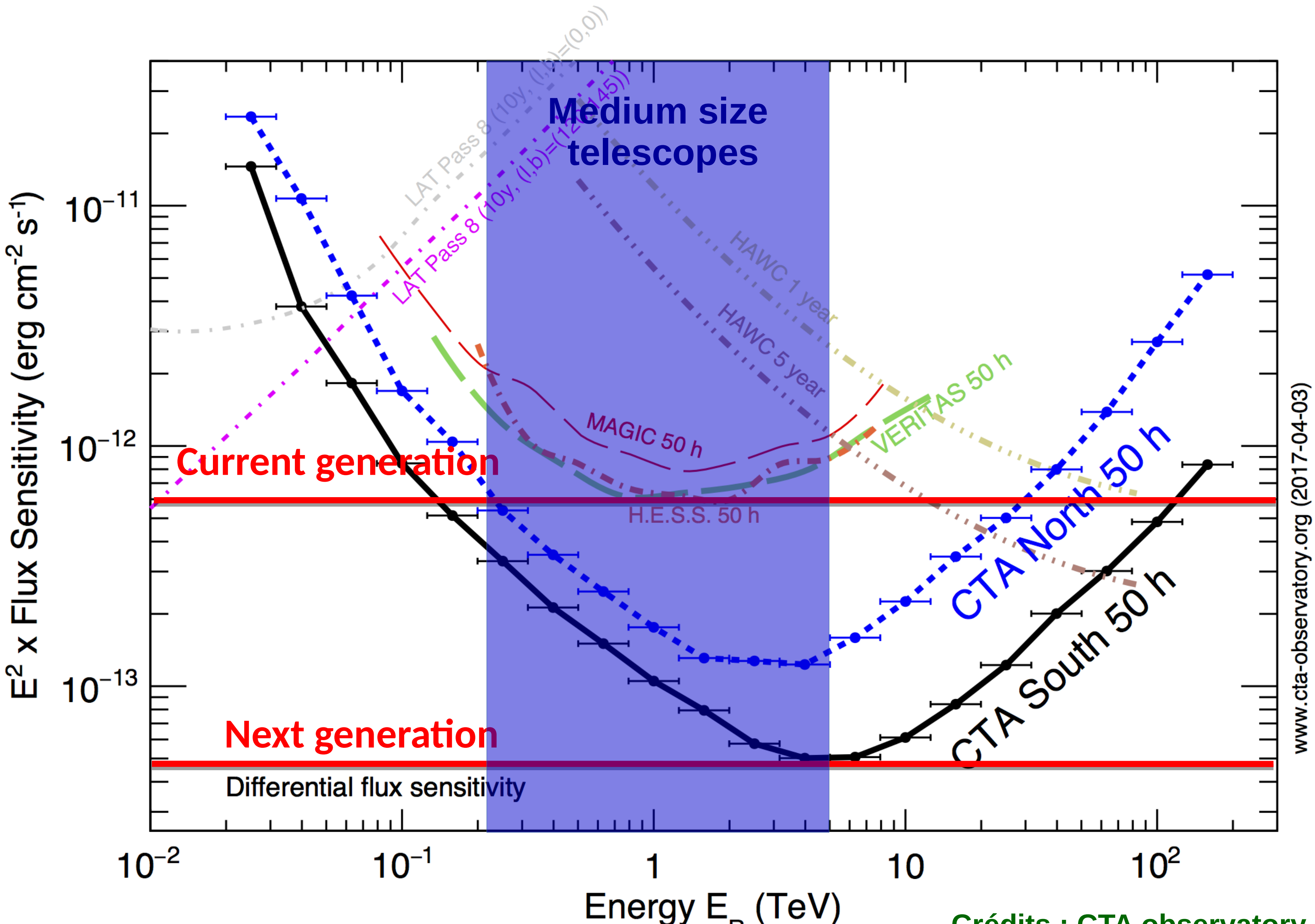

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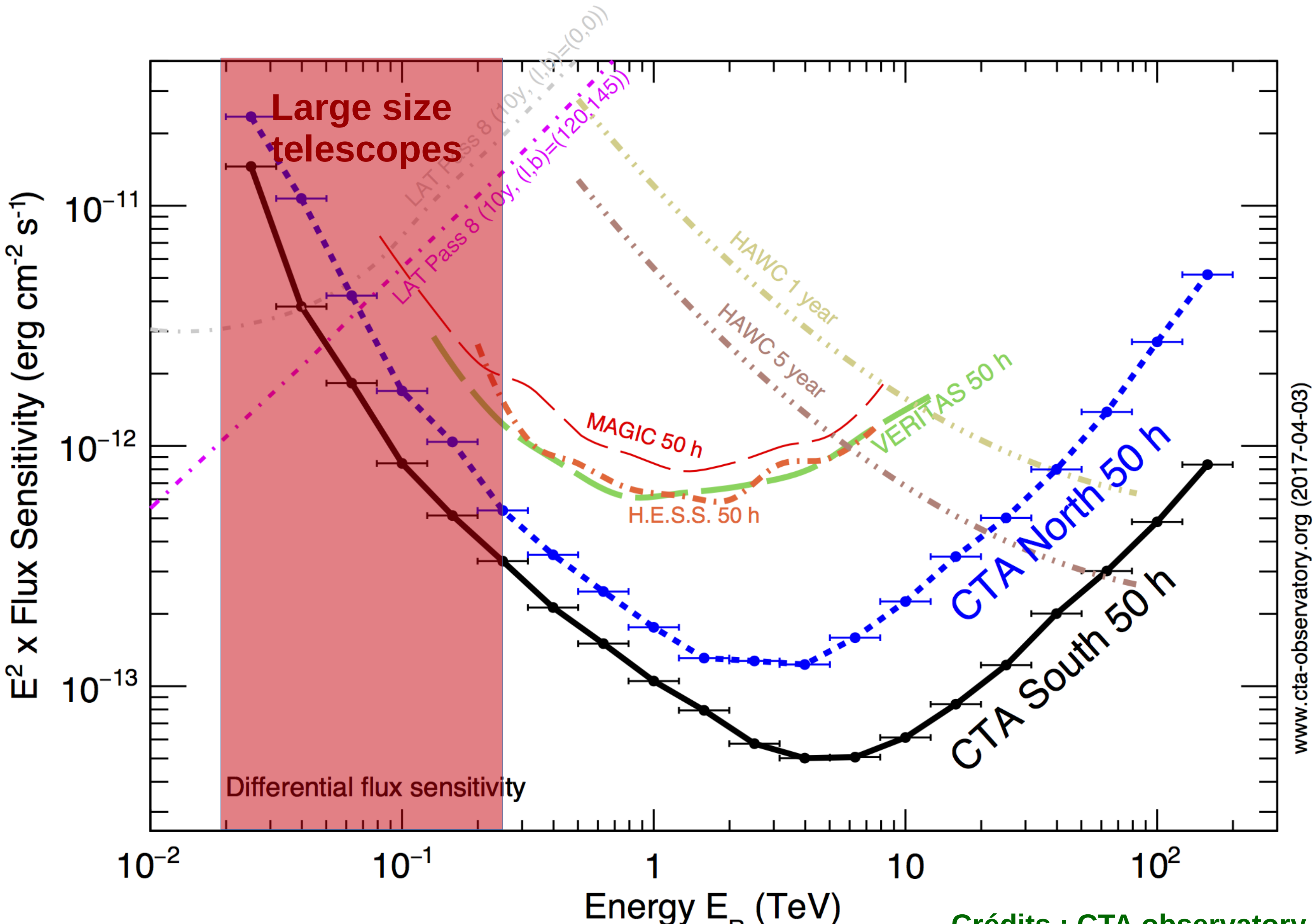

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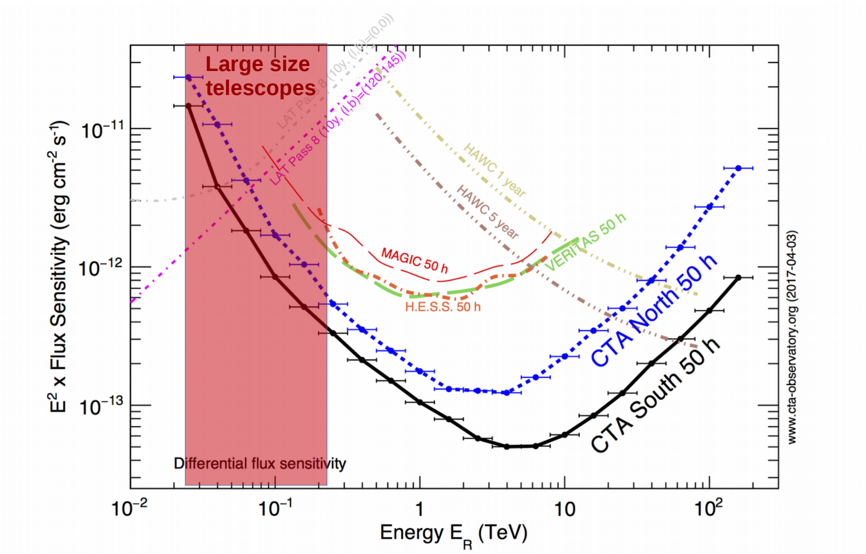
The science cases for the LSTs



- Transients:
  - → GRB
  - → AGNs
  - → Binaries
- Pulsars
- Extragalactic Background Light

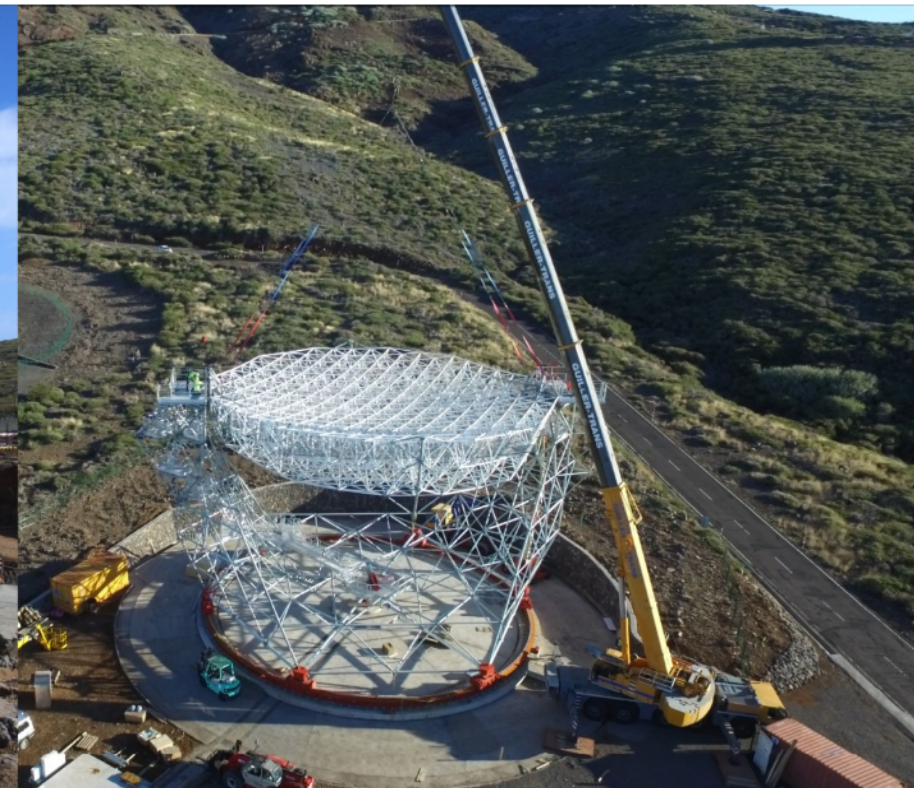
Fast repositioning
and large collection area is required

The first on-site telescope

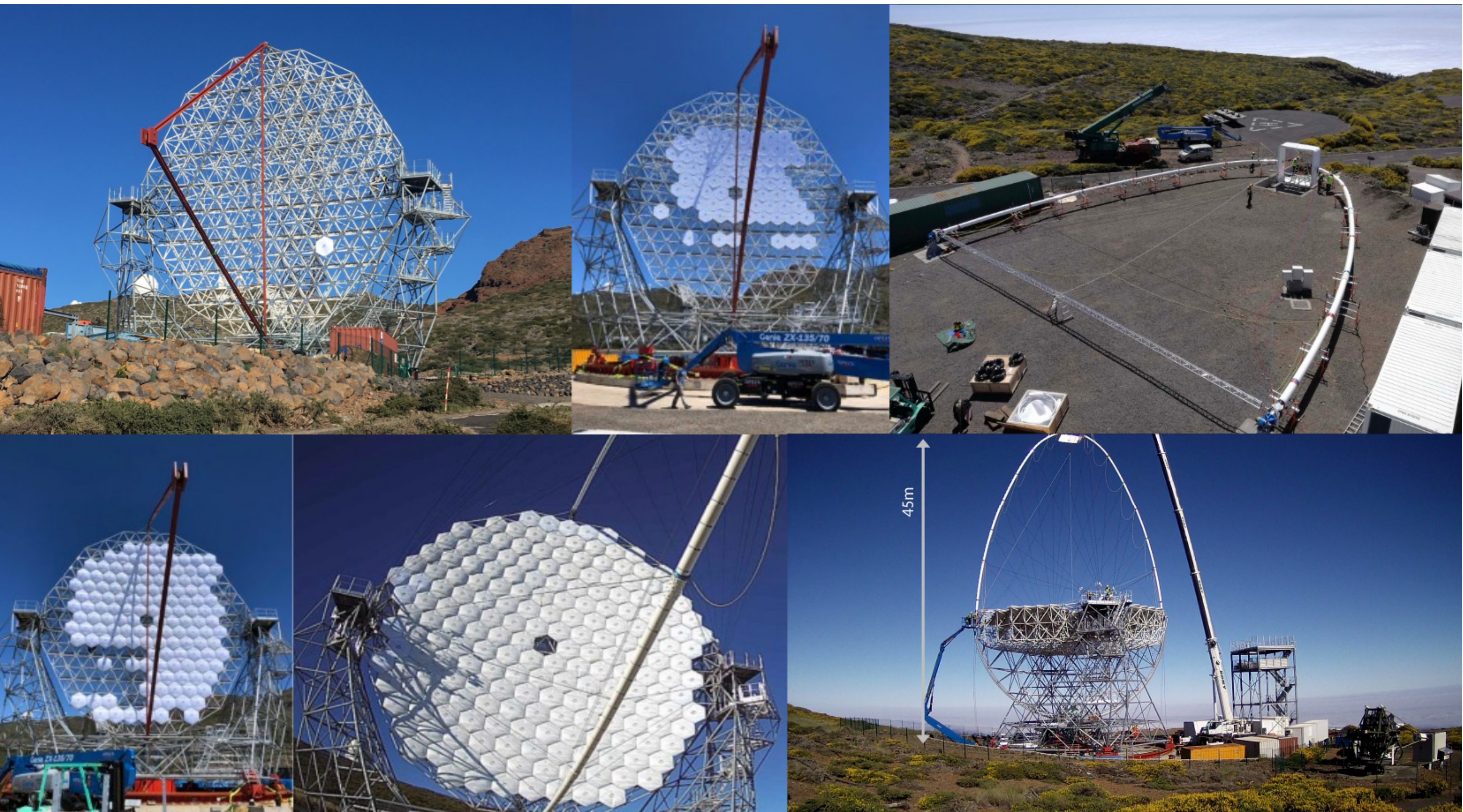
- **Optics:**
  - Parabolic primary mirror of 23 m diameter and 28 m focal length
  - Primary dish made of 198 hexagonal segments
  - Effective mirror area is 368 m²
- **Focal plane:**
  - Made of 1855 photo-multipliers (PMTs)
  - Pixel field of view of 0.1°
  - Total field of view of 4.5°
- **Structure:**
  - Maximum time for repositioning is 20 seconds
  - Total weight of the telescope is ~120 tons

Construction of LST-1

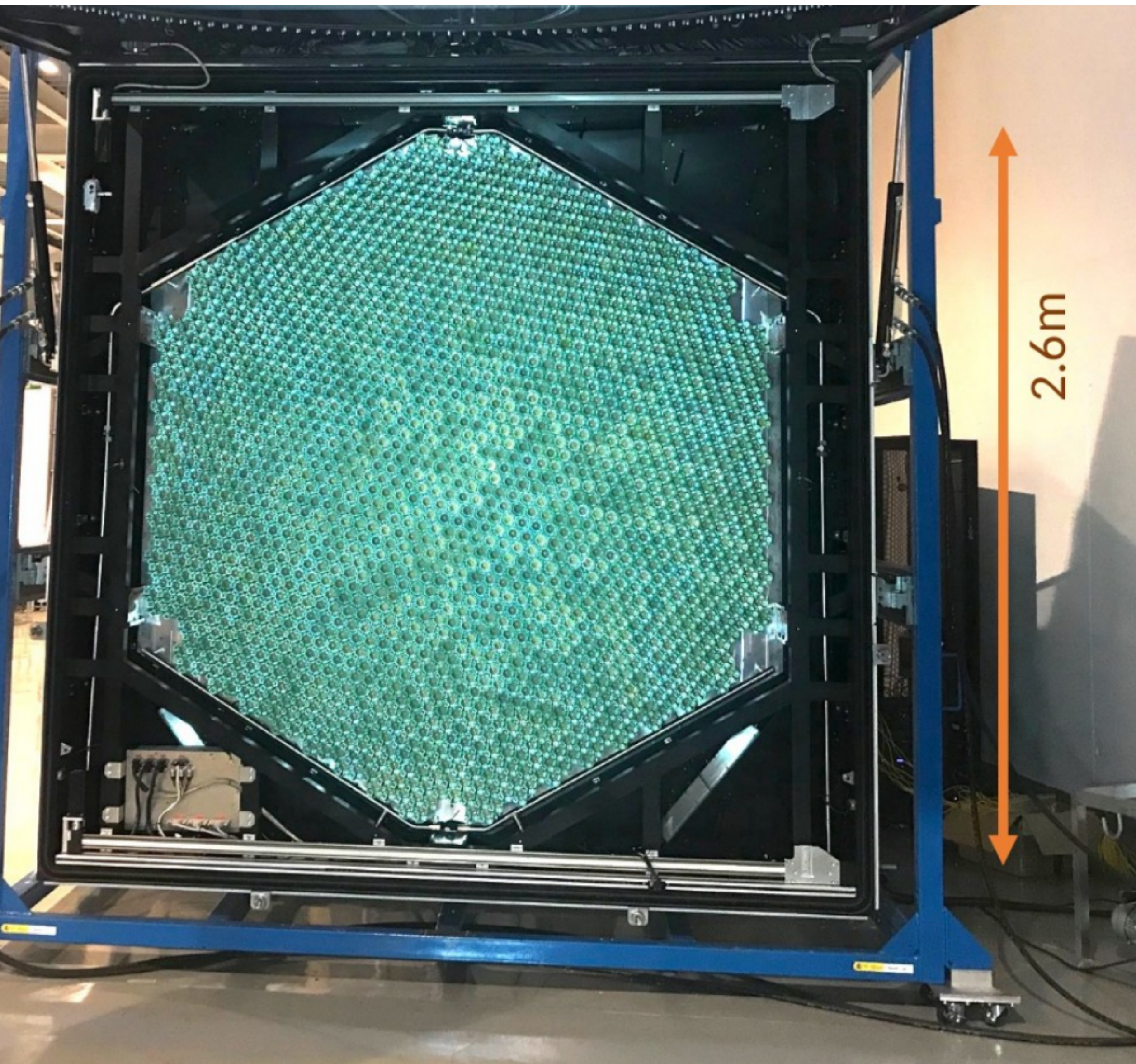
Construction started spring 2016

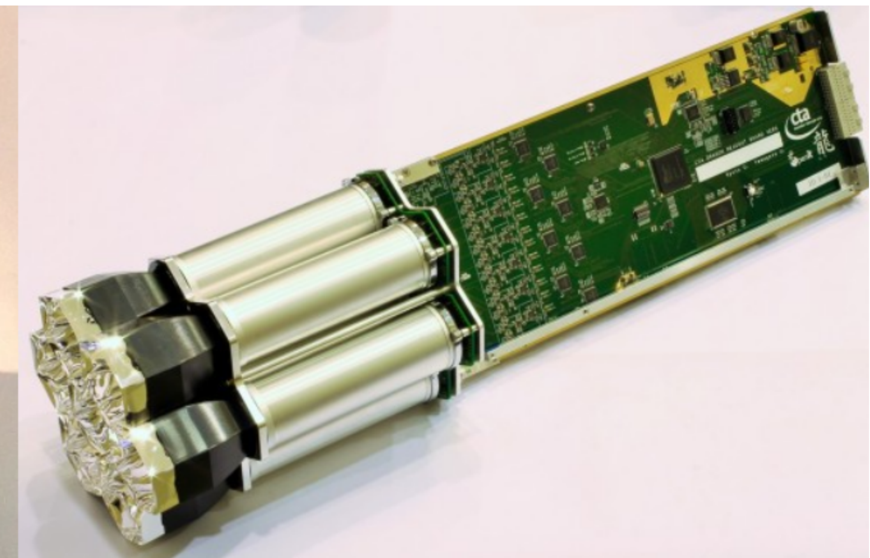


Mirrors and arch installation



Camera integration and installation

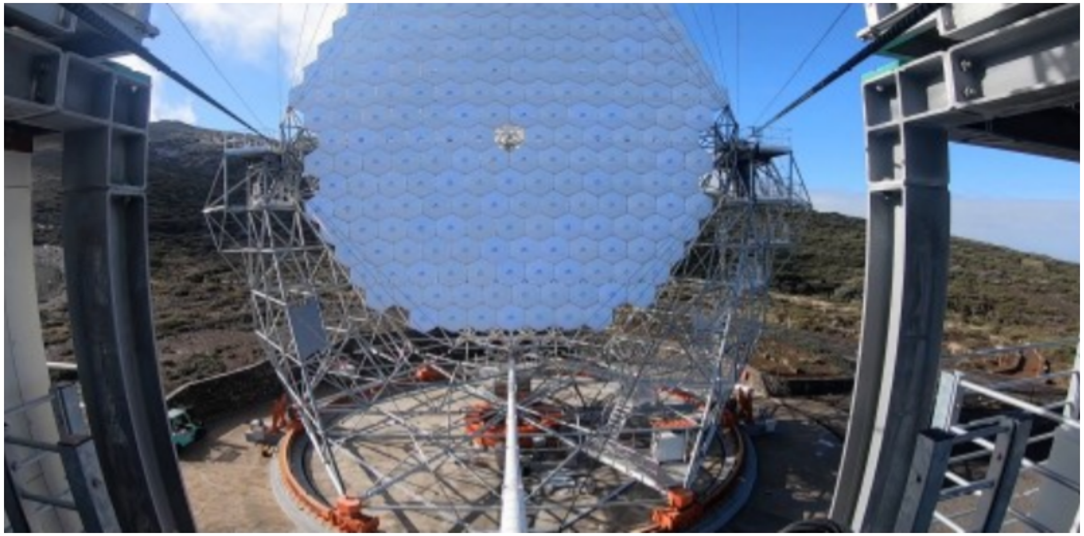


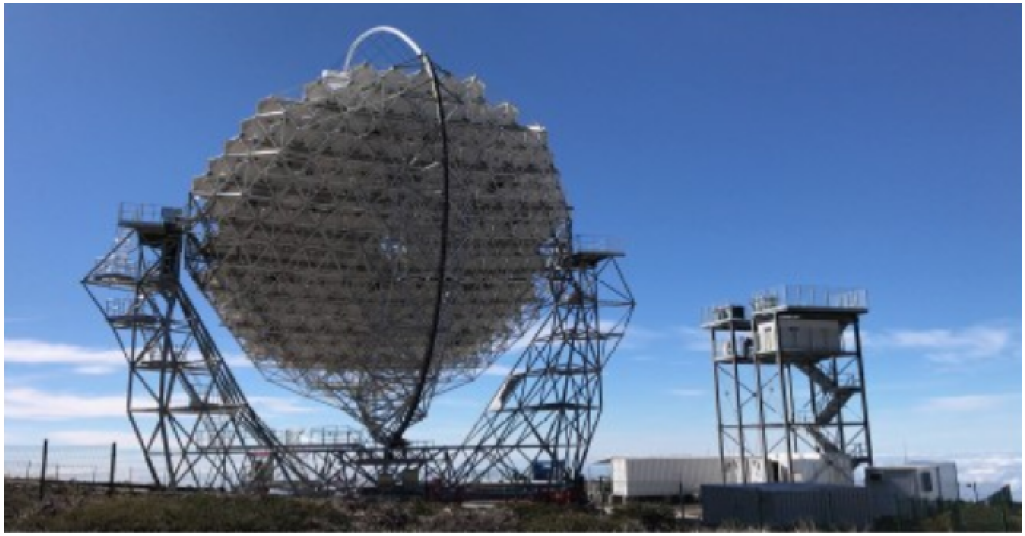


Inauguration 10th October 2018

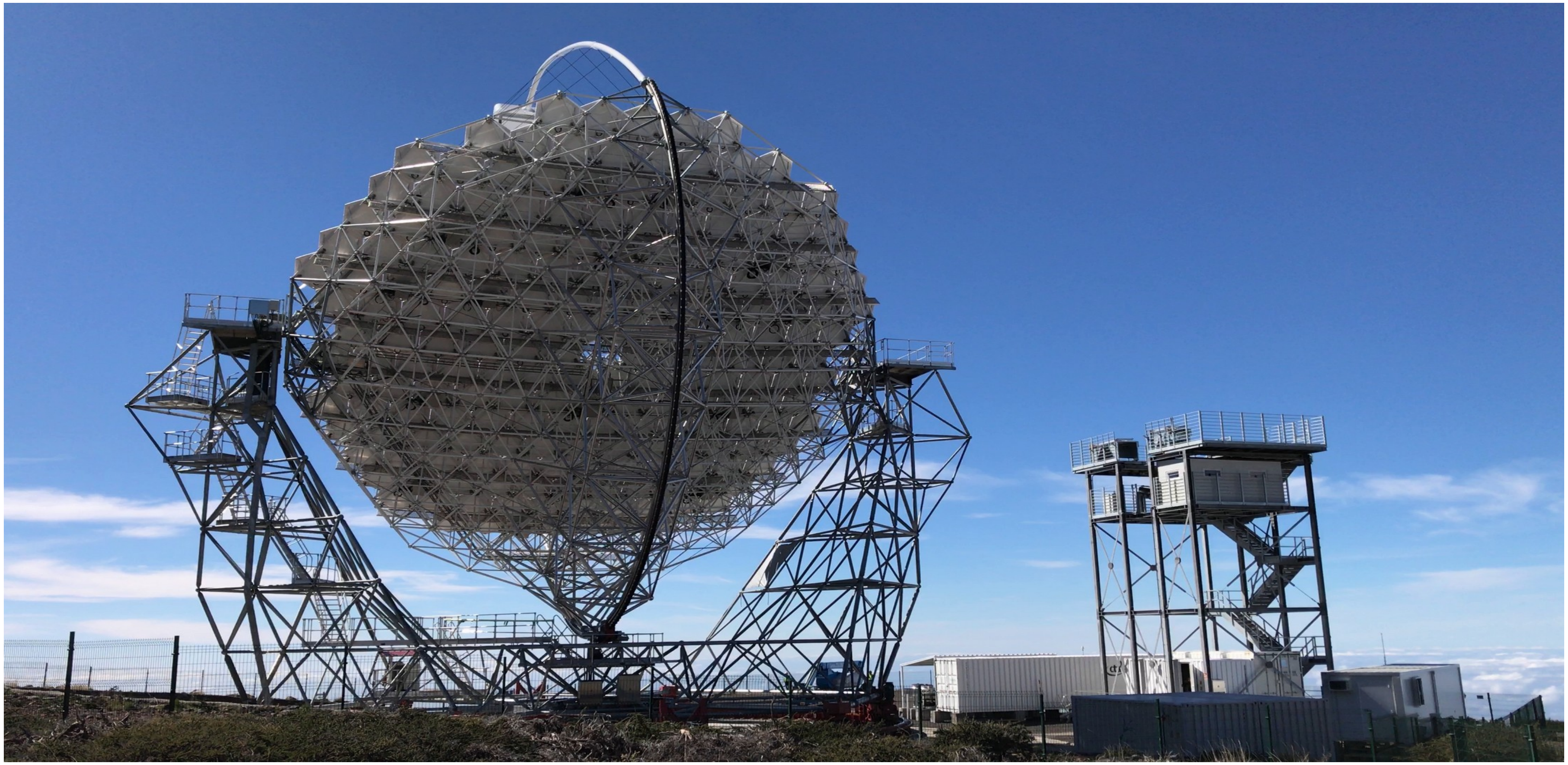
Fast repositioning

- → 20 seconds for 180° rotation in azimuth (33 seconds for 360°)
- → Drive speed regulation working as expected
- → Emergency stops tested and correctly handled
- → Fulfills the requirements



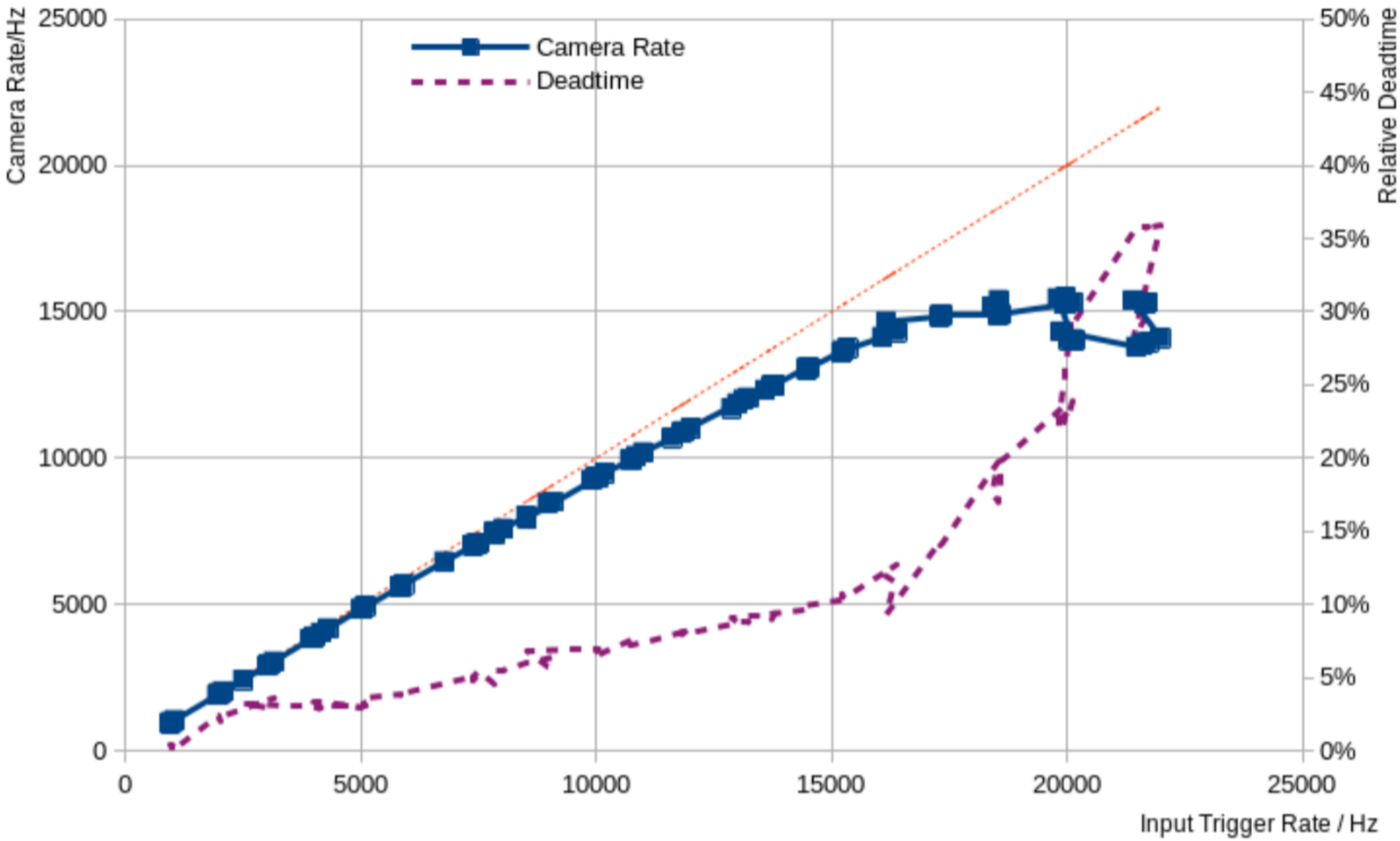


Drive speed test



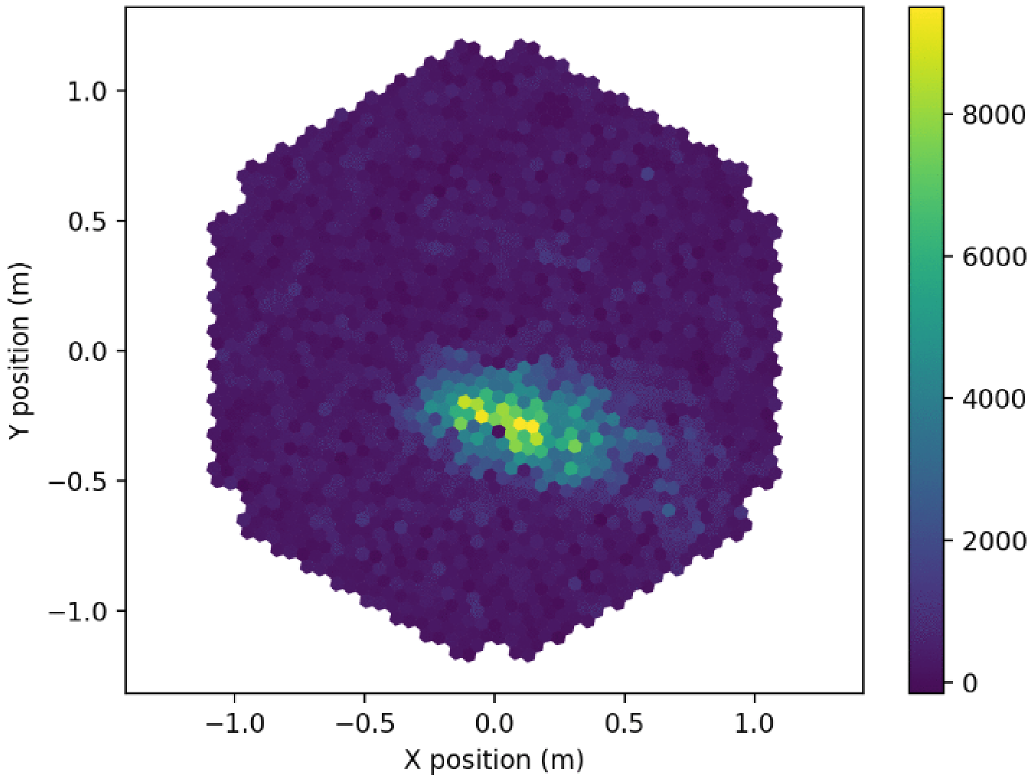
Fast acquisition rate

→ **Acquisition rate reaches 15 kHz with random trigger**

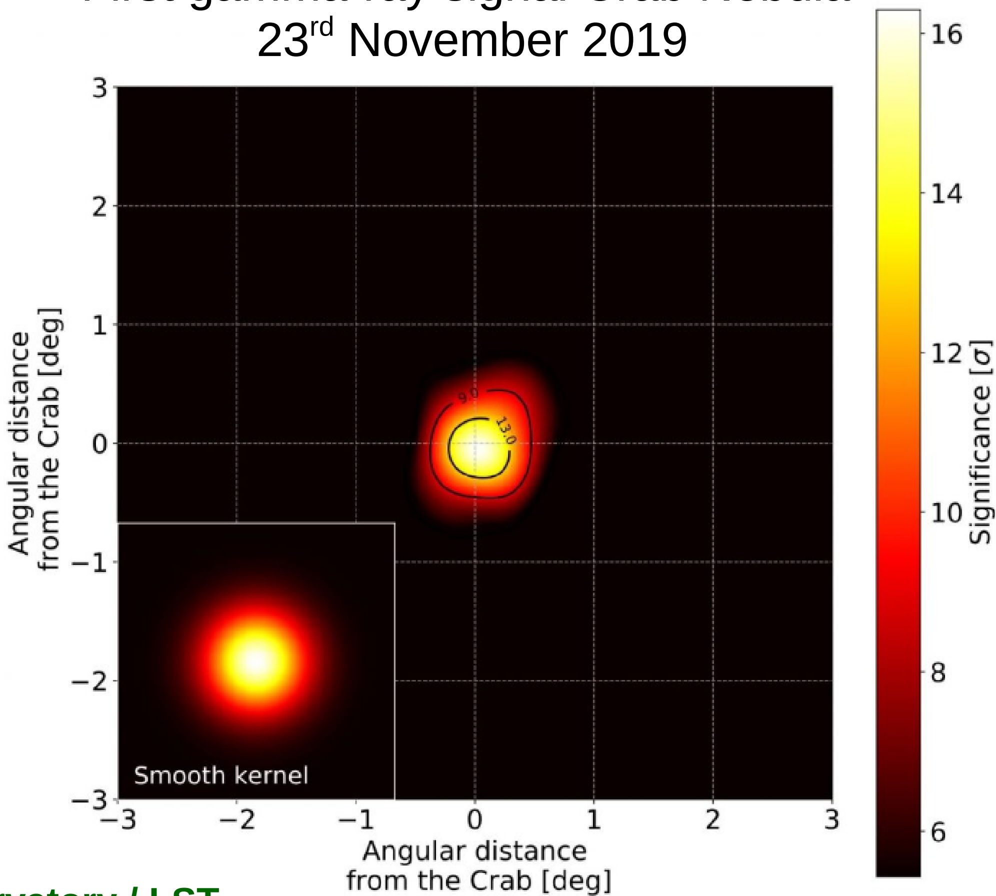


First observations

First Cherenkov light, 15th December 2018



First gamma-ray signal Crab Nebula
23rd November 2019



Crédits : CTA observatory / LST

GRB with the LSTs

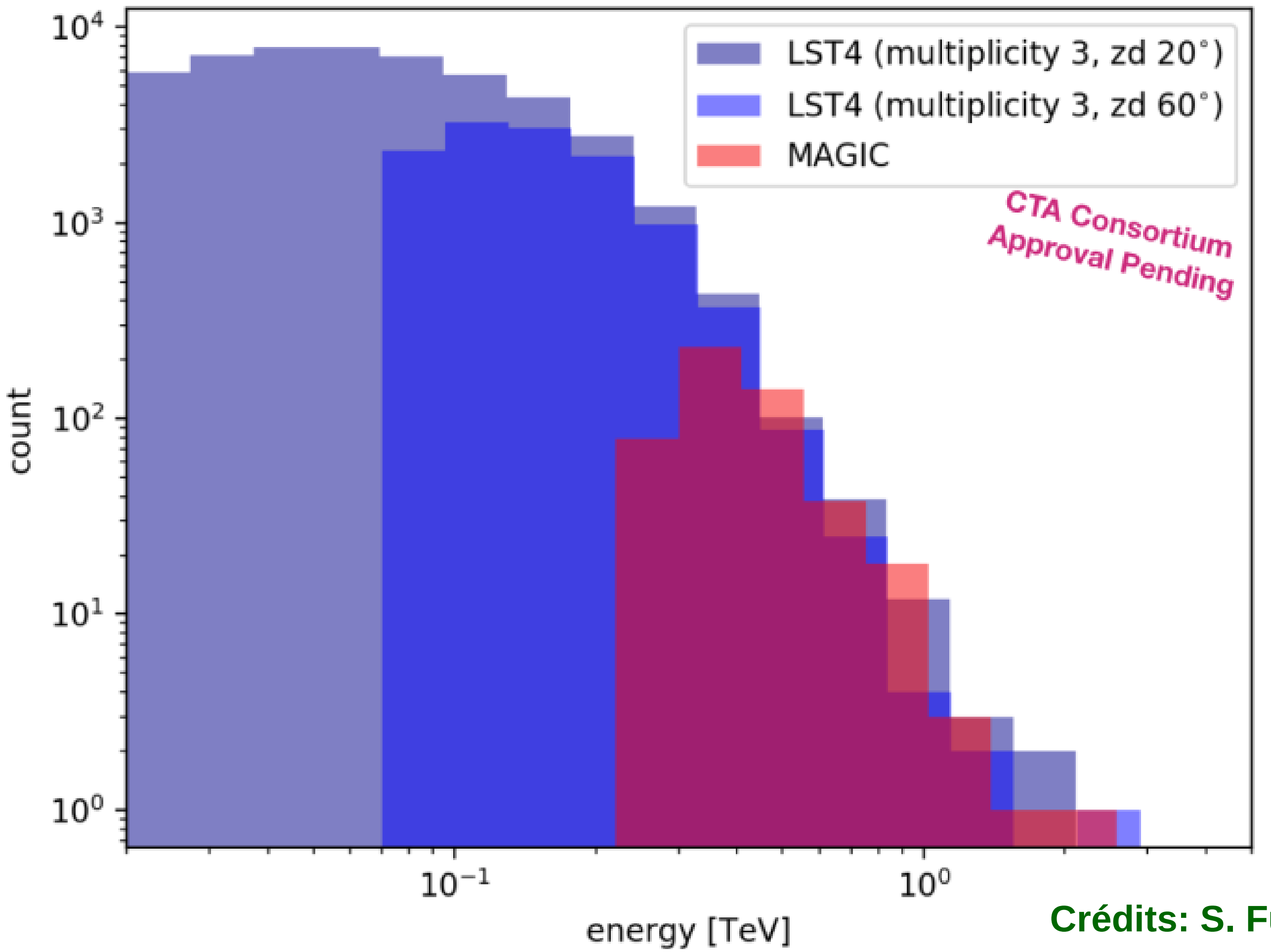
The case of the LSTs of CTA:

- Lower energy threshold → more events detected
- Faster repositioning → more events detected

What would GRB 190114C look for the 4 LSTs?

- Assuming observations by 4 LSTs during 100 sec at the La Palma site
- Using T_0 +62 sec and T_0 + 162 sec (where MAGIC and Fermi-LAT overlap) → not taking into account the faster repositioning
- ~450 events detected by MAGIC in this interval
- Requiring trigger from 3 out 4 LSTs (multiplicity 3)
- Assuming angular resolution of 0.15 degree at 100 GeV
- Assuming the intrinsic spectrum of GRB 190114C from MAGIC

Energy distribution of the events



Crédits: S. Fukami

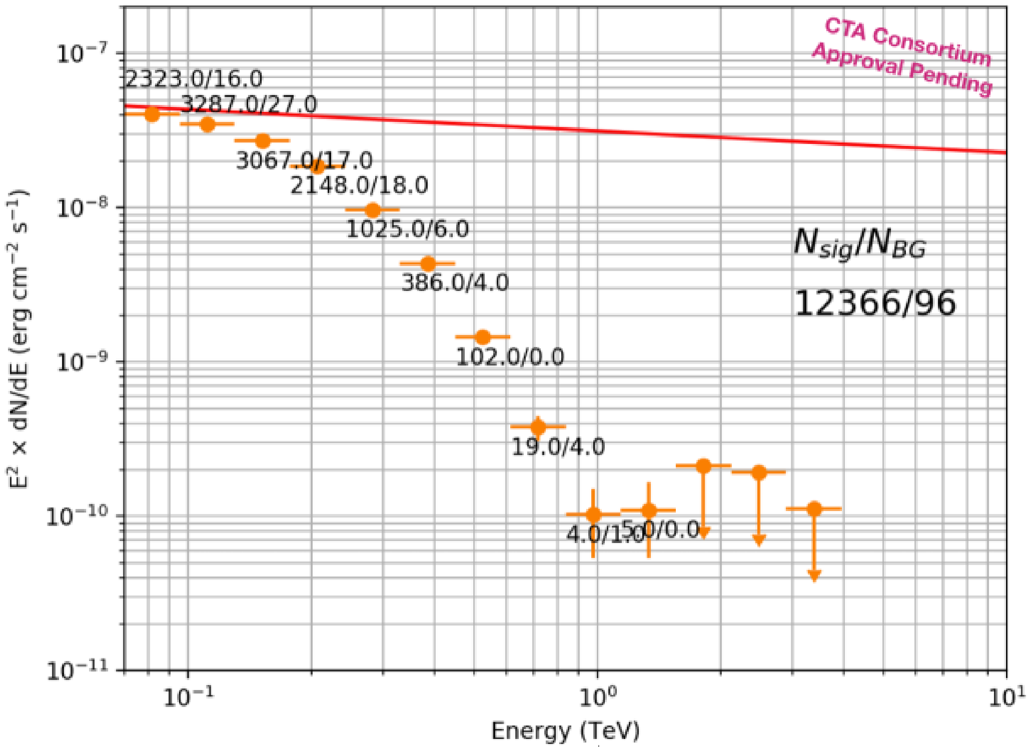
- Key role of the lower energy threshold
- **Relaxing trigger requirements to 2 telescopes would increase even more the numbers of events detected**

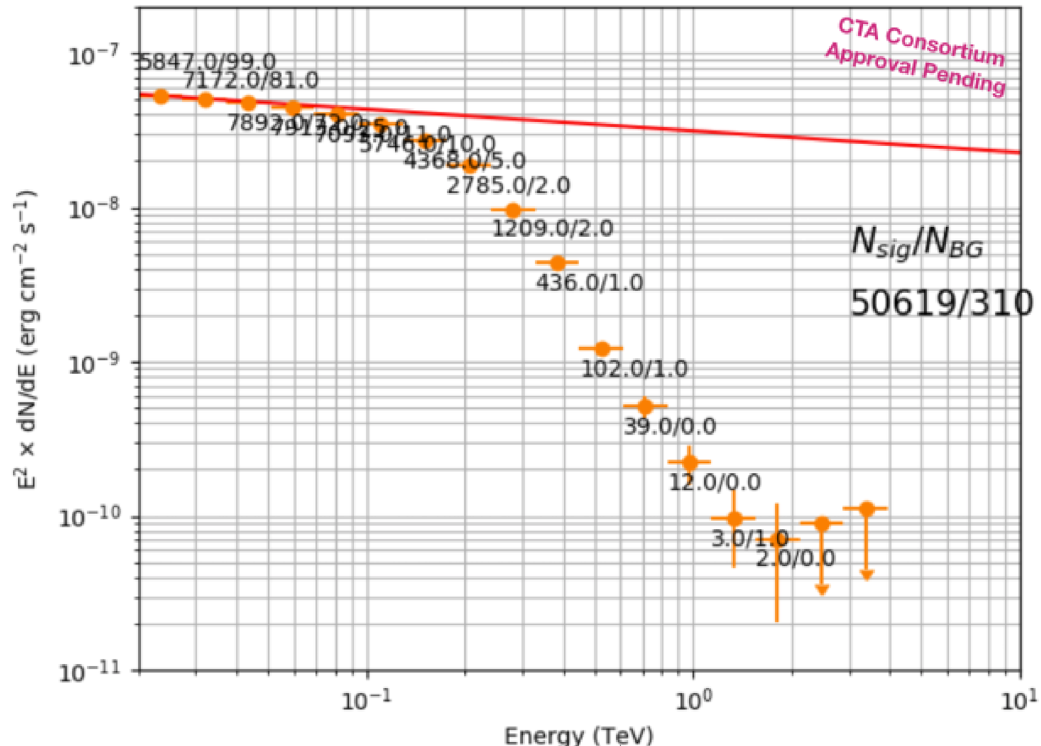
Expected spectrum

zenith angle = 60 °

Crédits: S. Fukami

zenith angle = 20 °





~ 30 times more events than MAGIC

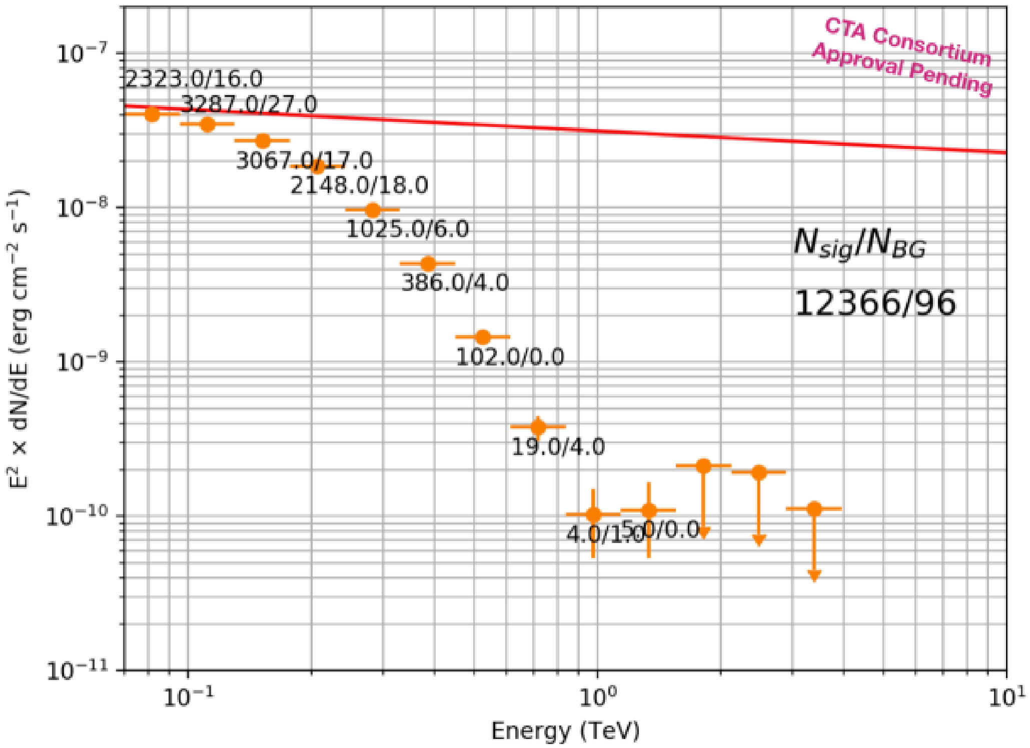
~ 100 times more events than MAGIC

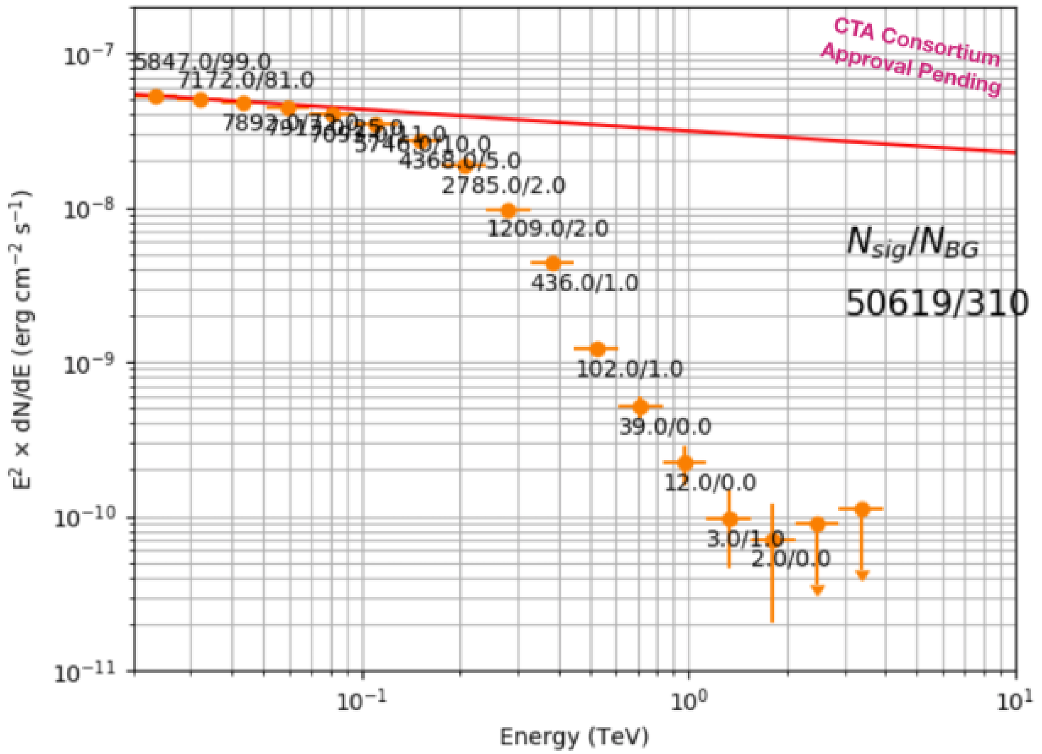
Expected spectrum

zenith angle = 60 °

Crédits: S. Fukami

zenith angle = 20 °





→ can be divided in much shorter time bins

→ Extreme scenario (time bin of 2 seconds): 20 events per energy bin, ie a statistical error ~ 20%

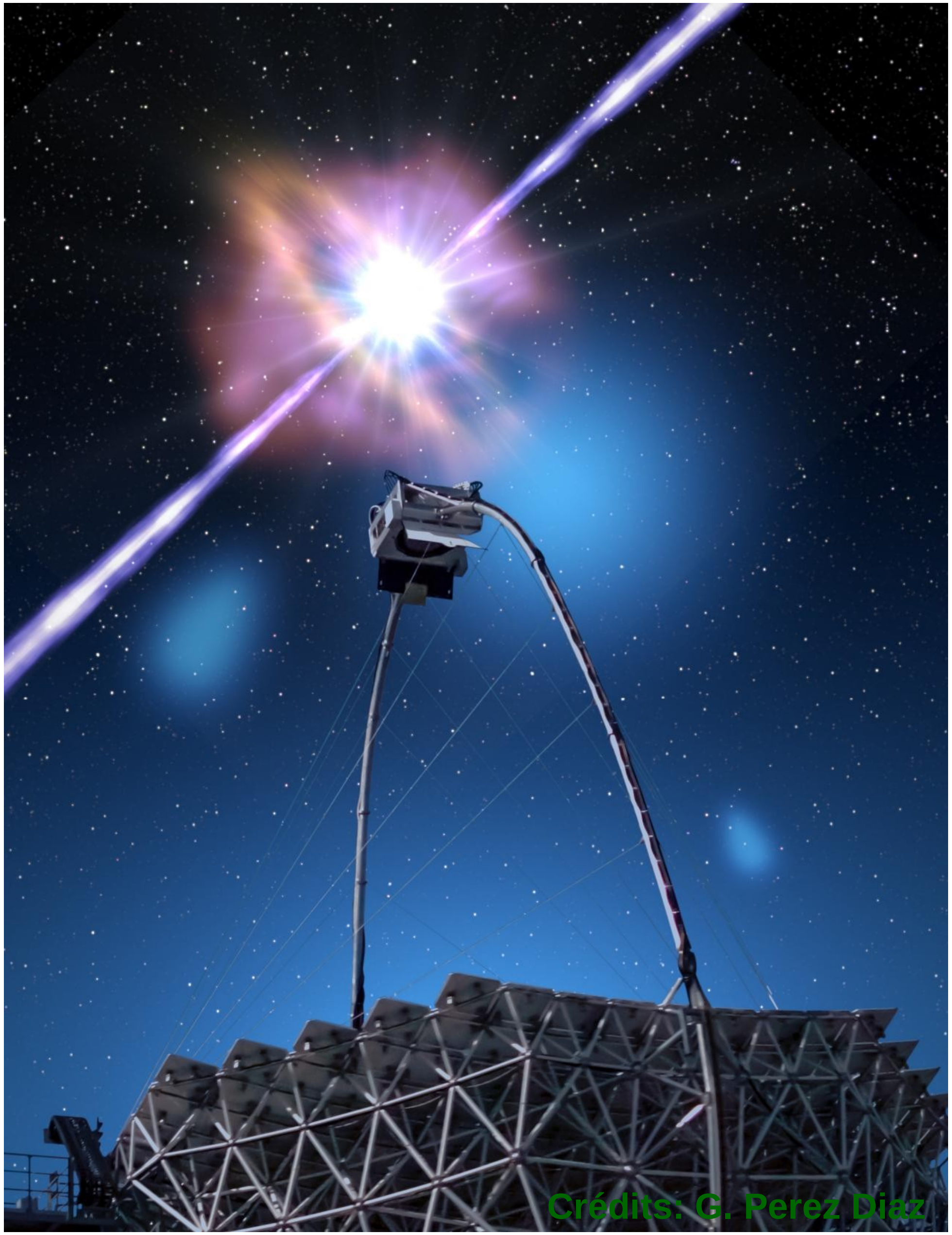
Conclusions

→ First GRB observed at TeV

→ New era starting for multi-messenger/multi-wavelength astronomy

→ LST will allow great improvements for those detections

- LST-1:
  - Built in 15 months in La Palma Spain
  - commissioning phase
  - scientific operation already started
- LST-2-4:
  - Many elements already built
  - civil works expected to start mid 2020
  - Completion of the northern site LST sub-array foreseen in 2023



Thanks for your attention