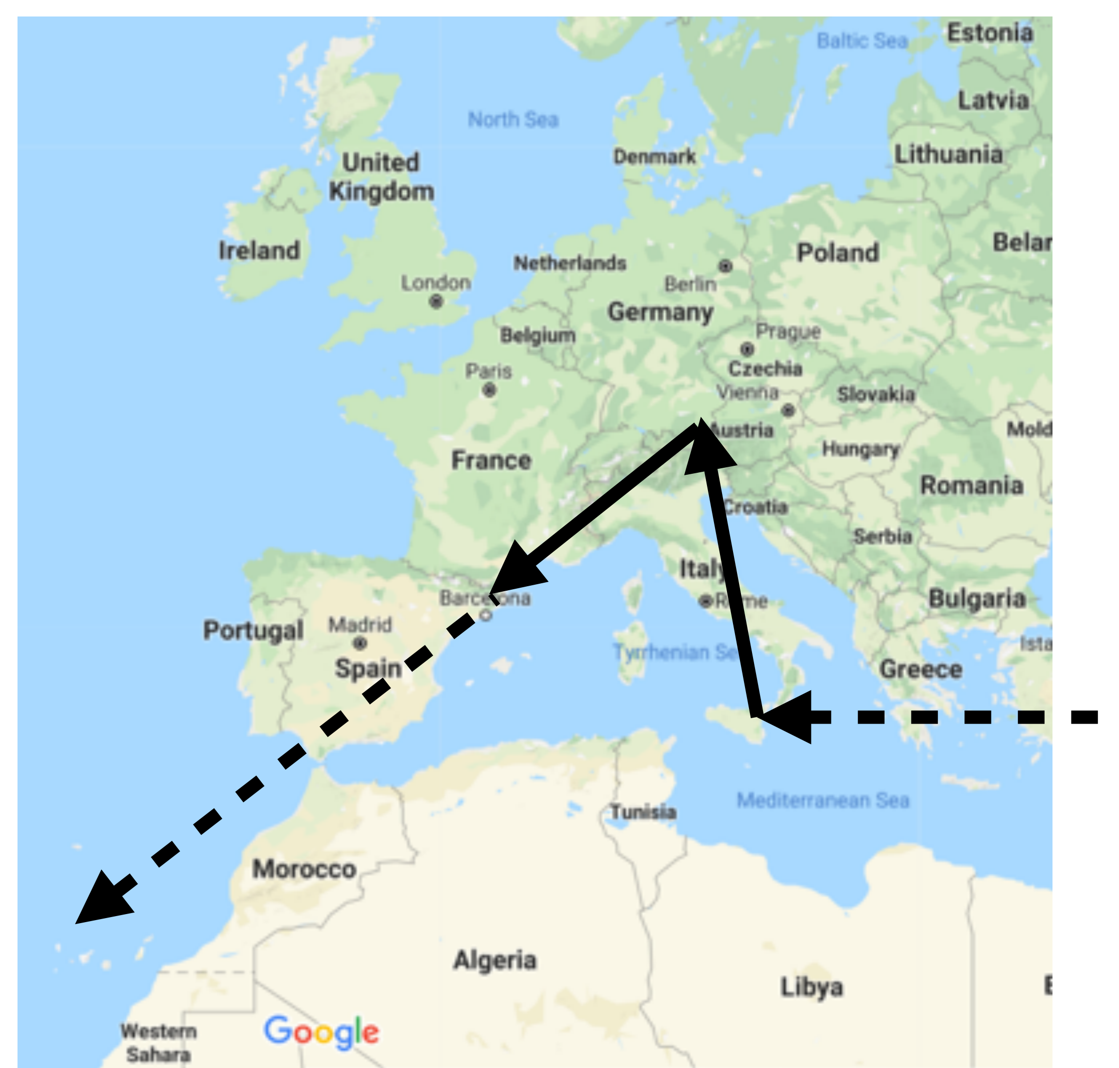
Gamma-ray burst physics with MAGIC and CTA LST

Koji Noda (ICRR)

25 May 2018
ICRR seminar

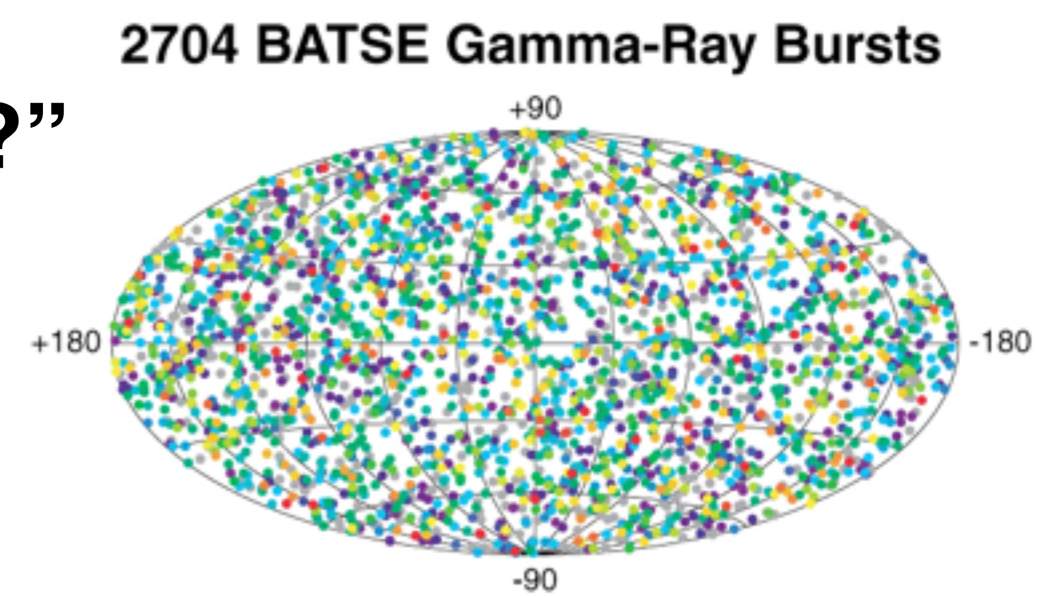
Self introduction

- PhD in ICRR, Univ. **Tokyo** in 2010, for astro-particle neutrino physics (Ashra experiment on Hawaii Island)
- 2-yr postdoc in INFN Catania, **Italy**, working in a collider experiment (LHCf), for particle shower physics
- 4-yr postdoc in Max-Planck-Institute for Physics, Munich, **Germany**, for Very High Energy gamma-ray astro-particle physics (MAGIC & CTA)
- 1.2 yrs in IFAE, Barcelona, **Spain,** as a Marie-Curie fellow, continuing MAGIC & CTA, with GRB physics
- Back to ICRR since the last Feb



Gamma-Ray Bursts (GRBs)

- Discovered in 1960's by a military satellite:
  "short, fading gamma-ray emissions from Universe"
- Location unknown until 1990's:
  "in our Galaxy, or extra-Galactic?"
  - BATSE on CGRO satellite found a uniform distribution (1992).
    Extra-Galactic, probably.

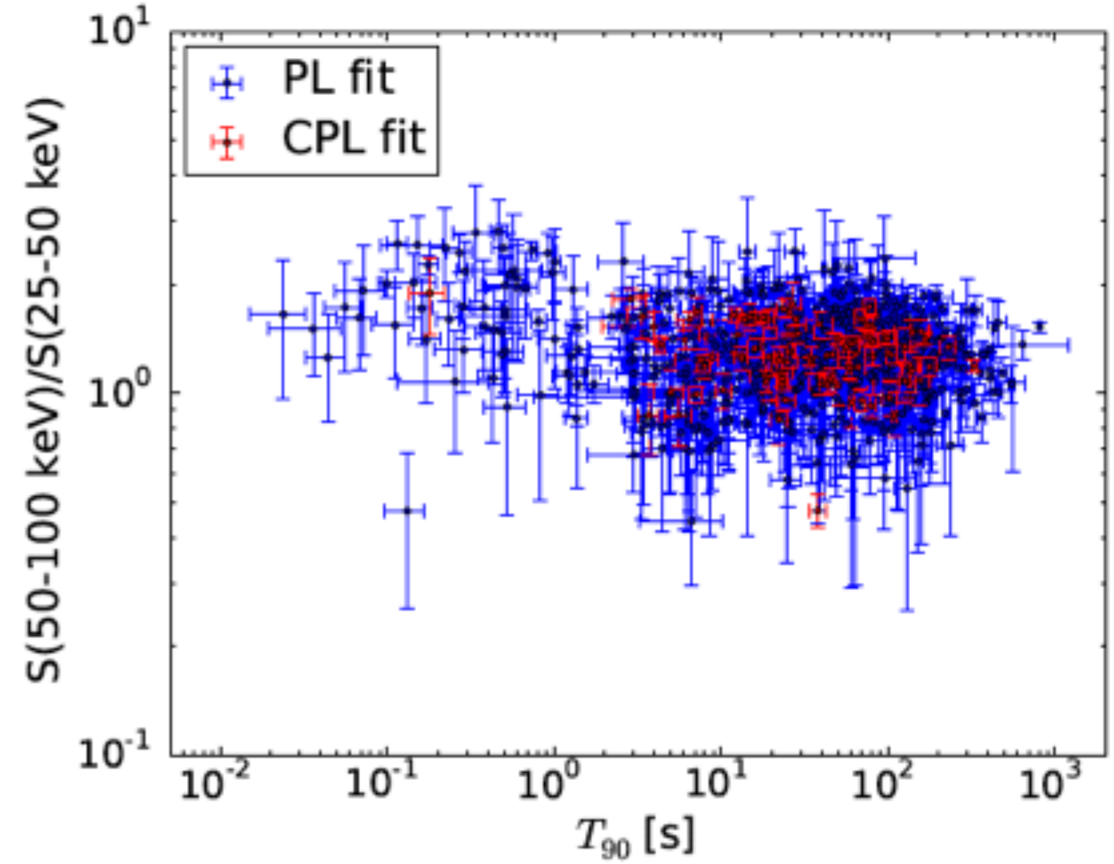


- BeppoSAX and its followup almost confirmed a (**partial**) **supernova association** (GRB980425 & SN1998bw)
  - finally done by HETE-II et al. with GRB030329 = in 2003.
  - next GRB-dedicated satellite! *Swift* (2004 - now)

New class of objects in the 21st century

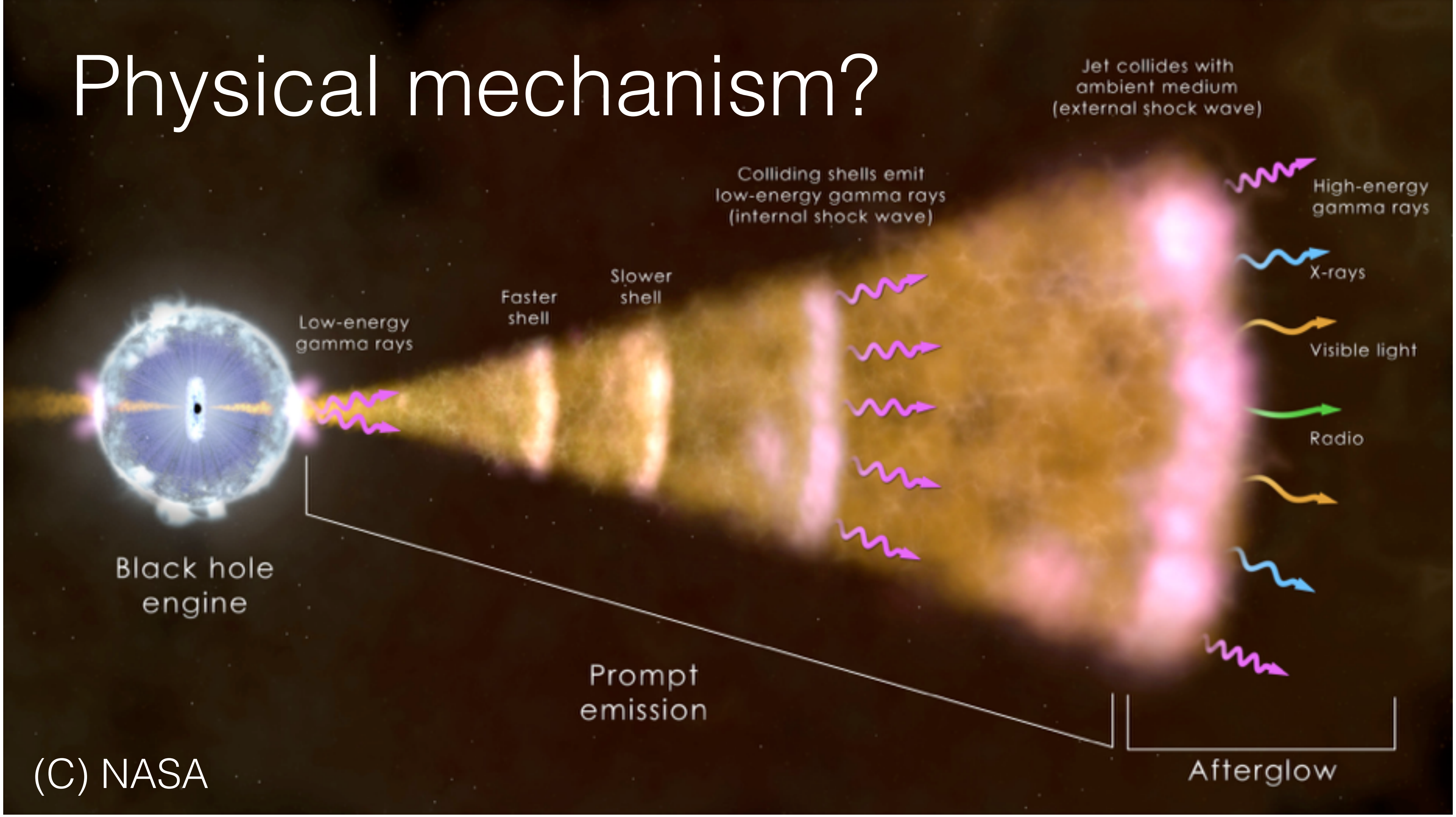
GRB classification

- Quick localization and alert to telescopes on the ground
  - Tons of studies for >10 yrs
- **Classification** of GRBs
  (See e.g. the 3rd *Swift* BAT GRB catalog, Lien et al. arXiv:1606.01956)



- **Long** GRBs (typ. duration >2 s, ~70%, soft)
  associated with core-collapse SNe = <u>death of a massive star</u>
  Studied well, (almost) no controversy now
- **Short** GRBs (typ. duration <2 s, ~30%, hard)
  Probably <u>a merger of neutron stars (NS), or NS - Black hole</u>
  We need GW to confirm it. ***First example (?) in 2017***

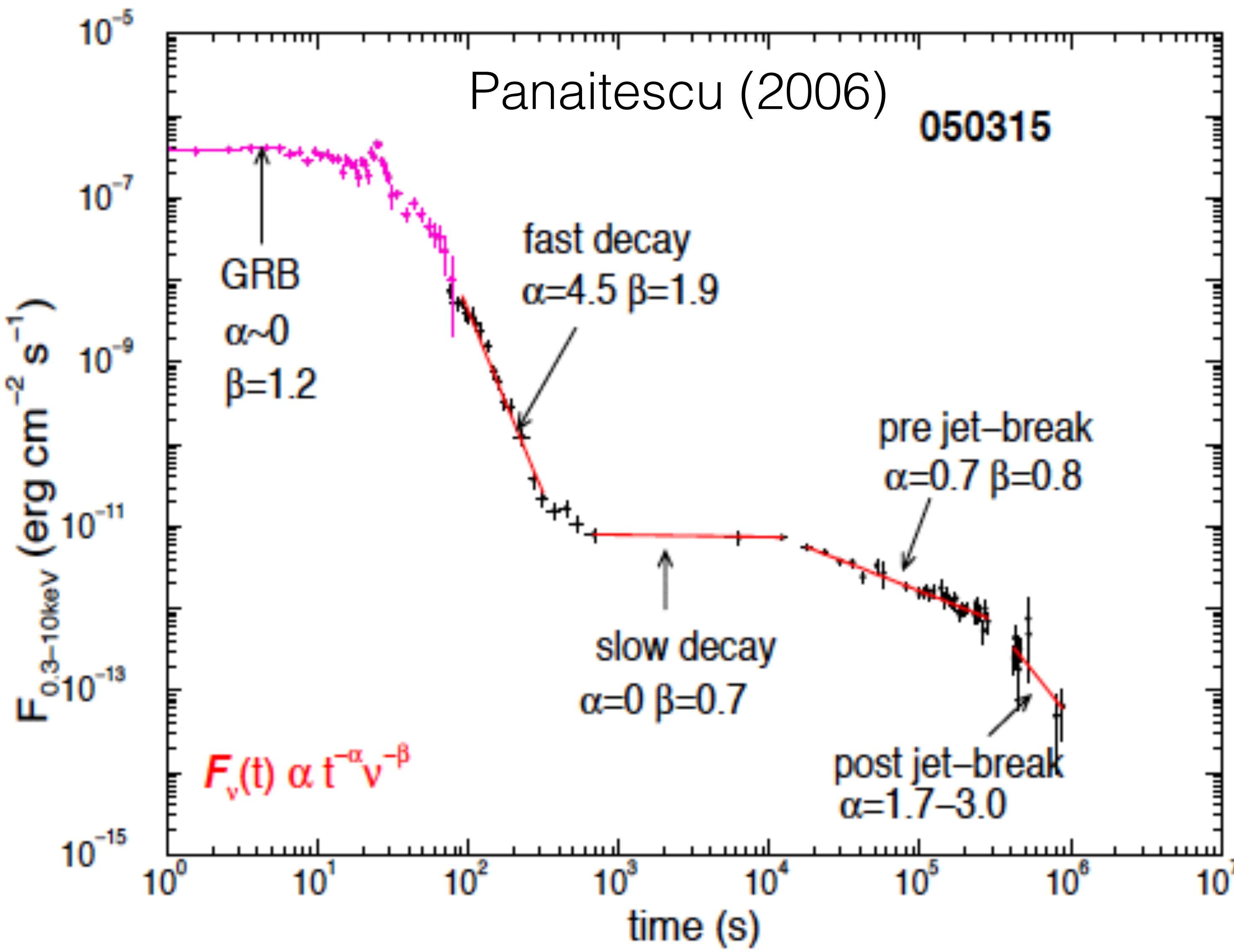
Physical mechanism?



Even if we know origins, **we don't know why gamma-rays are emitted**

- ***Afterglow*** (>~10^4 s): well-known late emissions in X-ray, optical and radio
    - jet + interstellar matter = shock wave. Accelerated e's emit synchrotron.
- ***Prompt*** emission (<~10^2 s): is GRB "itself", but is unknown.
    - Very efficient (complicated?) mechanism is required in the jet ejecta

“Standard” (X-ray) lightcurve



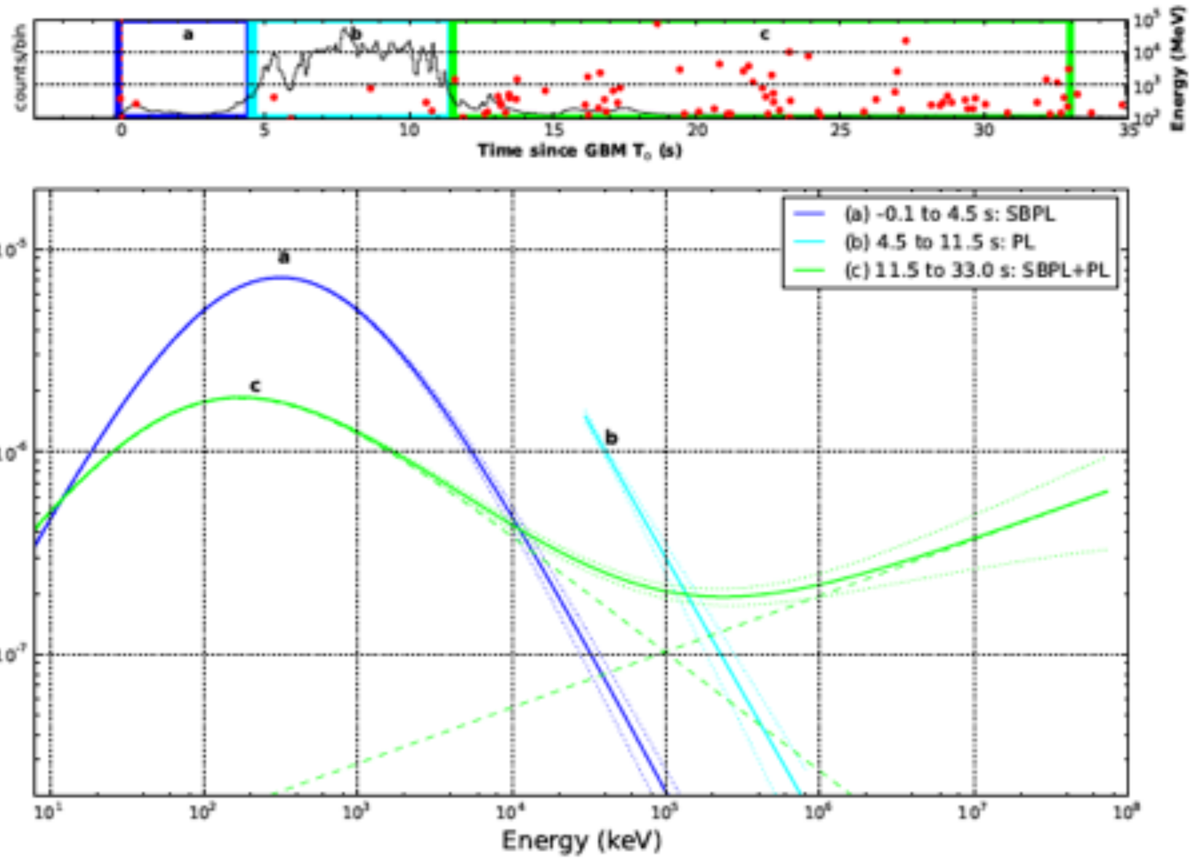
Connection between prompt and afterglow is much unclear even in X-ray. Slow decay is a rather common feature.

<u>After the end of prompt emission, something is happening.</u>

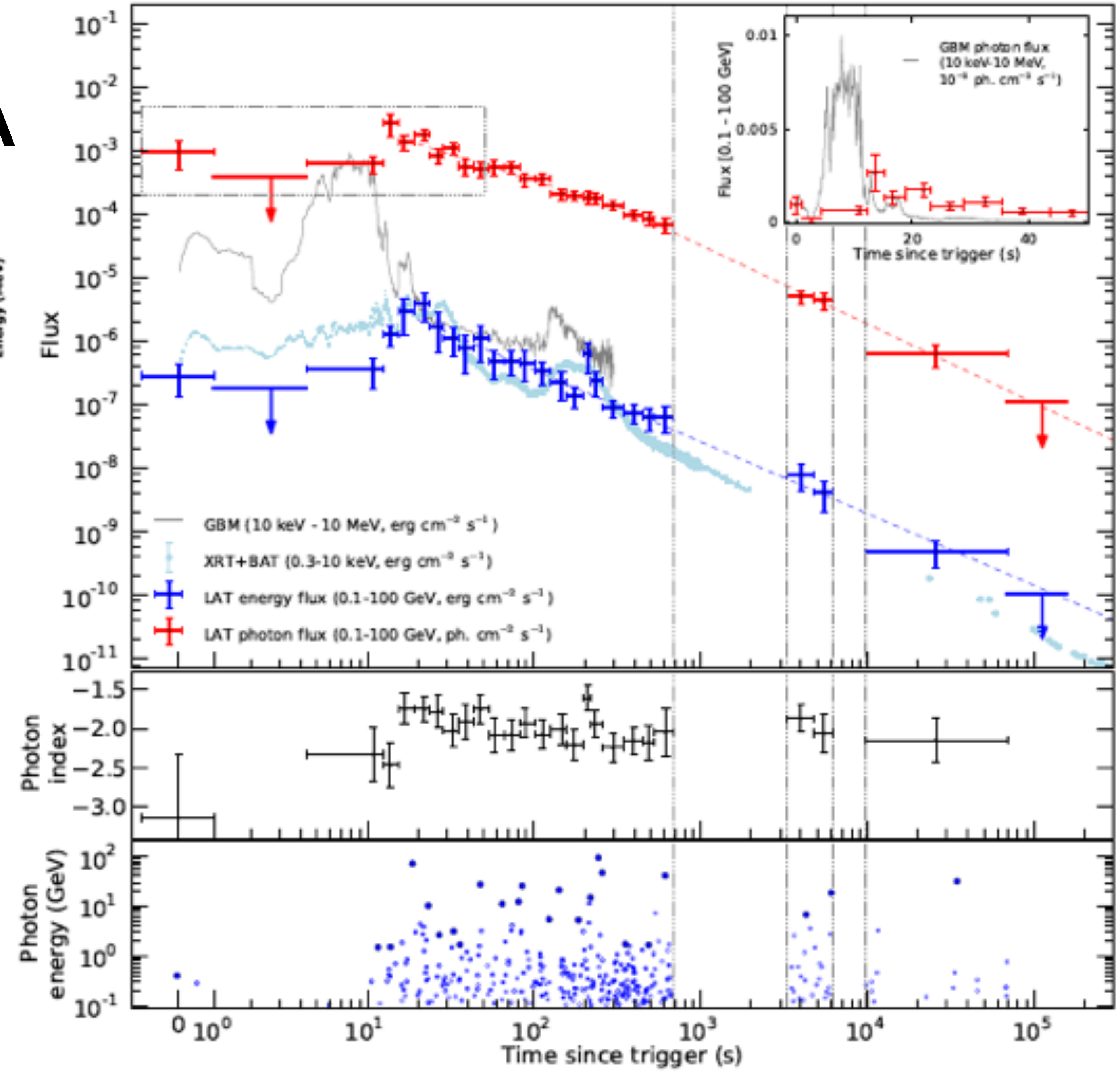
GeV GRBs

- **’Gamma-Ray’ above is < ~MeV.** We need more information. How about higher energy (100 MeV ~ 10 GeV) ?
- **EGRET** on CGRO
  - >100 MeV γs from 4 GRBs consistent with synchrotron
  - but, GRB941017 has **another HE component** (<200 MeV)**, with a delay of ~200 s** (reported only in 2003)
- **LAT** on *Fermi* observed 35 GRBs with >20 MeV in 2008 - 2011. ~140 GRBs as of now. E.g.,
  - 090510: Even short GRB has a prompt HE emission (~30 GeV)
  - 090902B: 3 γs >10 GeV with a delay up to 80 s
  - and,,, **“the” GRB130427A**

GRB130427A

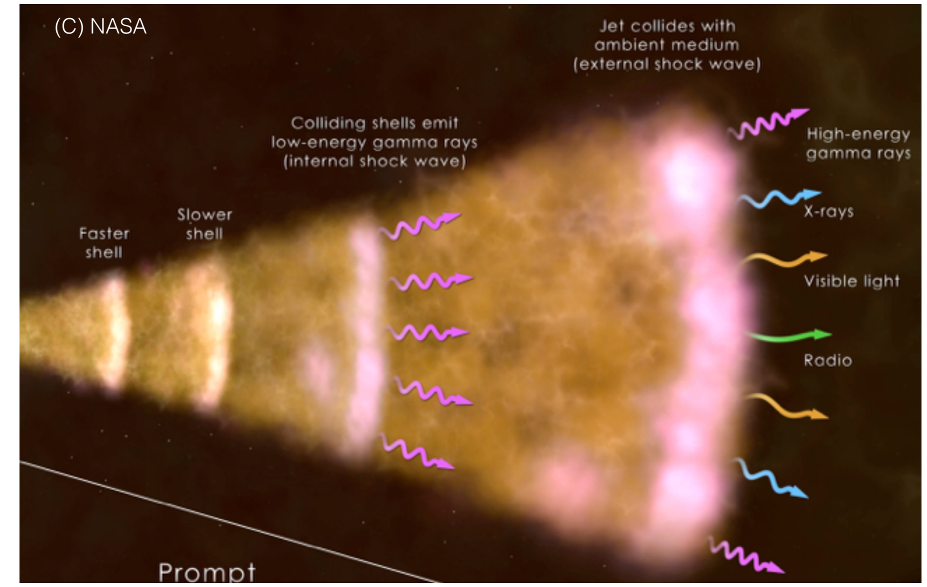


Ackermann et al. (2014)

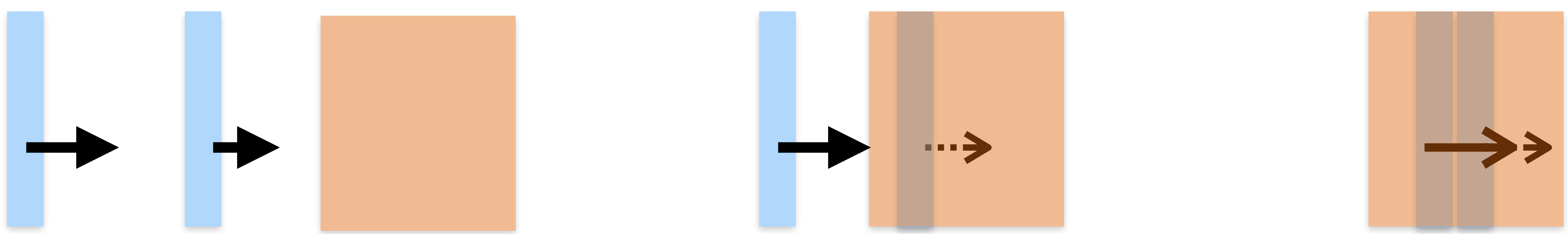


- 15 γs >10 GeV. **73 GeV** (19 s), **95 GeV** (4 min), **32 GeV (~9 h) !**
  - VHE γs are emitted mostly in the **late prompt - early afterglow,** even later than the slow decay phase (if any)?
  - Naturally, <u>not from the main component</u>, but how?
- **“faster obs is better”, but nice to know a short delay is acceptable**

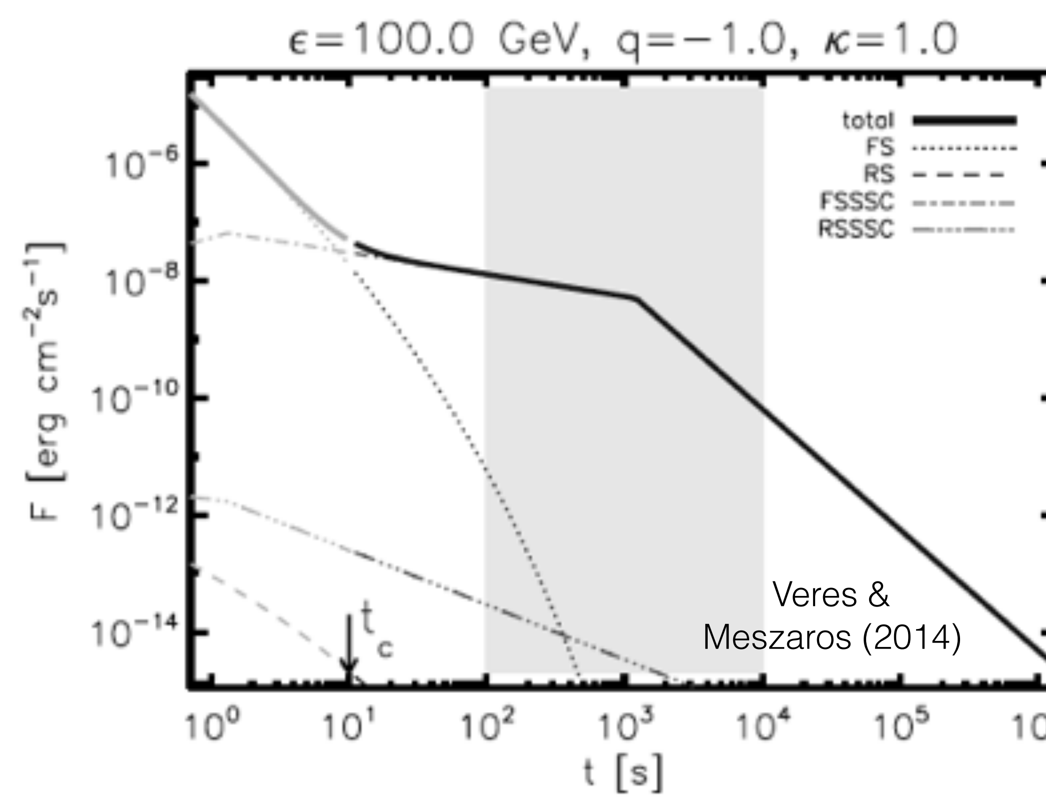
Mechanism?



- one of candidates: “**Refreshed shocks**”
  - Assumption: mixture of shell speeds (consistent with multi-peak prompt)

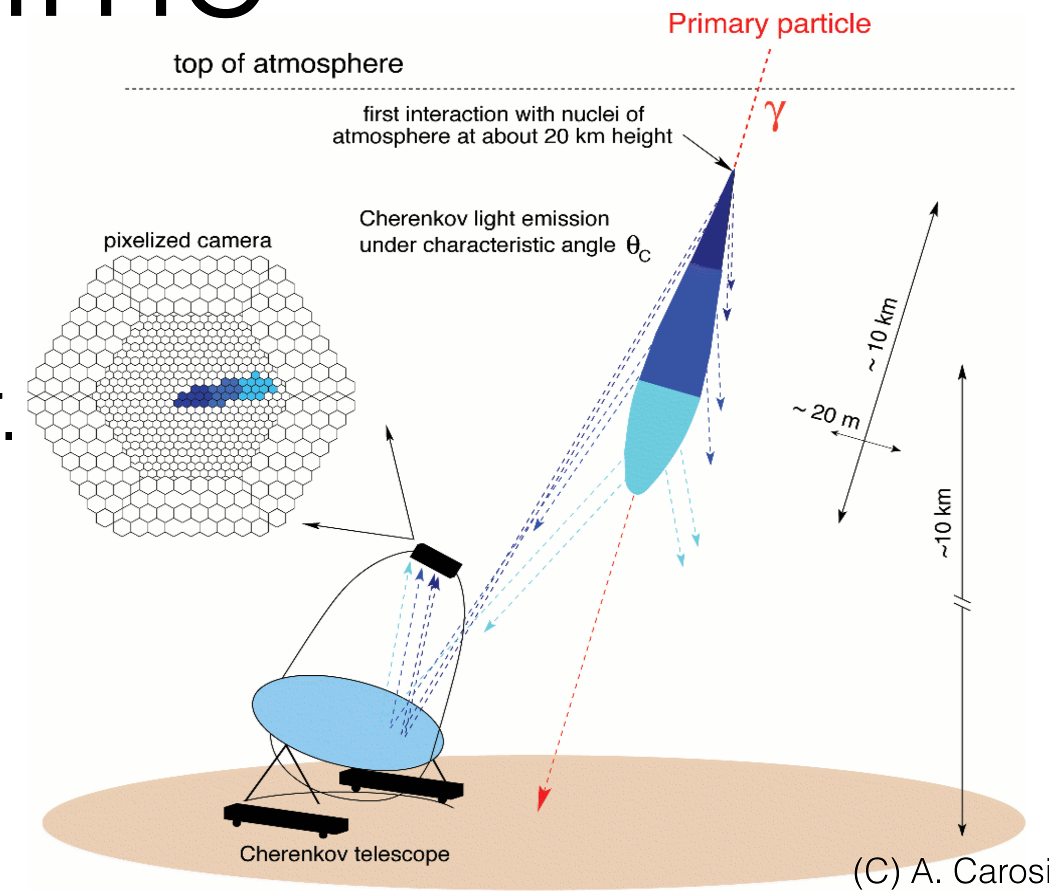


- E.g., Veres & Meszaros (2014) calculate GeV-TeV γs from short GRB, with this mechanism
  - ~10 GeV will have a peak at ~300 s
  - With a long activity in the central engine, **higher E can endure even for ~$10^{3\text{-}4}$ s**




Imaging Air Cherenkov Telescopes (IACTs)

Very High Energy (>10 GeV)
"IACT regime"



- In >10 GeV, **IACTs like MAGIC are more sensitive than satellites**, as the collection area is much larger.
- lower duty cycle, so <u>less probability</u>
- IF observed, GRBs will be detected by IACTs, but
  - Telescopes should react **fast** enough (as FoV is small) No strong need for O(1) s. O(10-1000) s is fine
  - **Energy threshold** should be as **low** as possible
  - GRB should be **close** enough to avoid the EBL attenuation. Nobody knows in advance, but **less EBL with lower E**

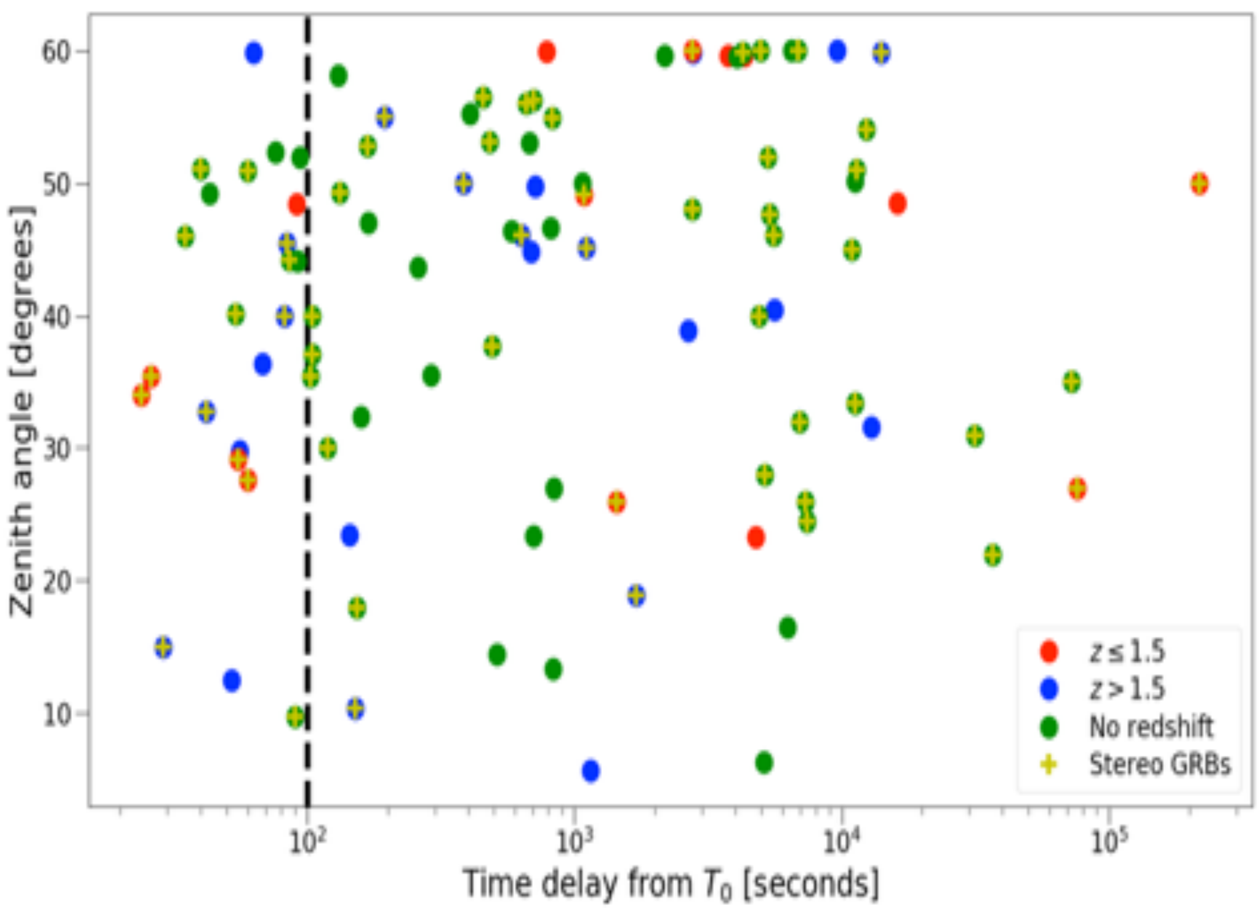
MAGIC telescopes

- ORM, La Palma, Canaries, Spain. 2200 m a.s.l., 2 x 17 m IACTs since 2009
- Sensitivity (50 h, 5σ, >220 GeV): ~0.66% Crab, Energy resolution: ~15% @ 1 TeV, ~23% @ 100 GeV, **Energy threshold: ~50 GeV, ~30 GeV (SumTrig)**
- Slewing speed: **7 deg/s (~25 s for 180 deg)**
- *MAGIC is the best IACT for GRB*, but no firm detection yet
  - “Good GRBs are always with a bad weather or with a bright moon” => Of course, due to a lower duty cycle. We should not give up.
  - “**Not only the best instrument**”: Strategy should be continuously updated with newest knowledge.

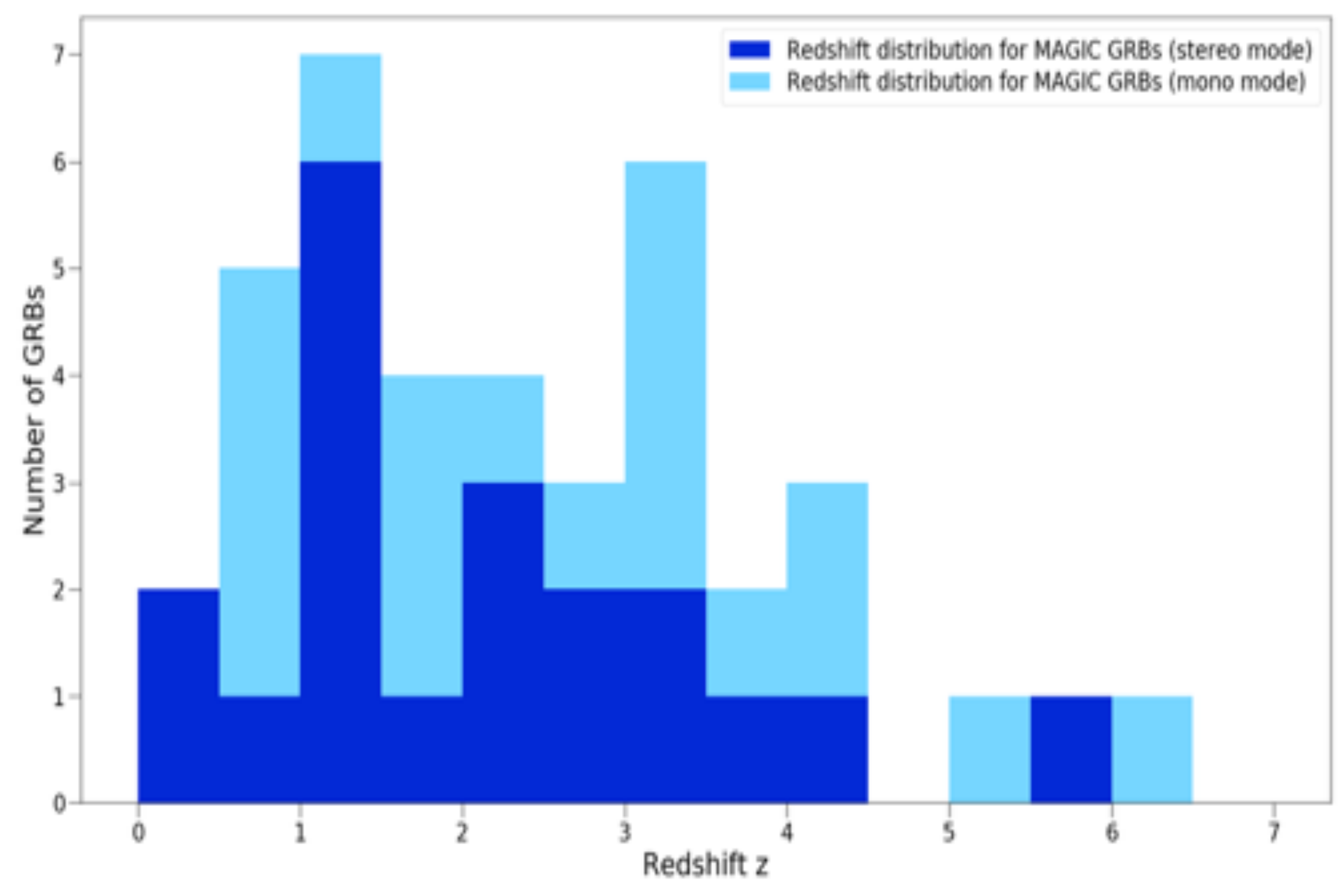
GRB obs. by MAGIC

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

Delay vs. Zenith angle



histogram of known redshift

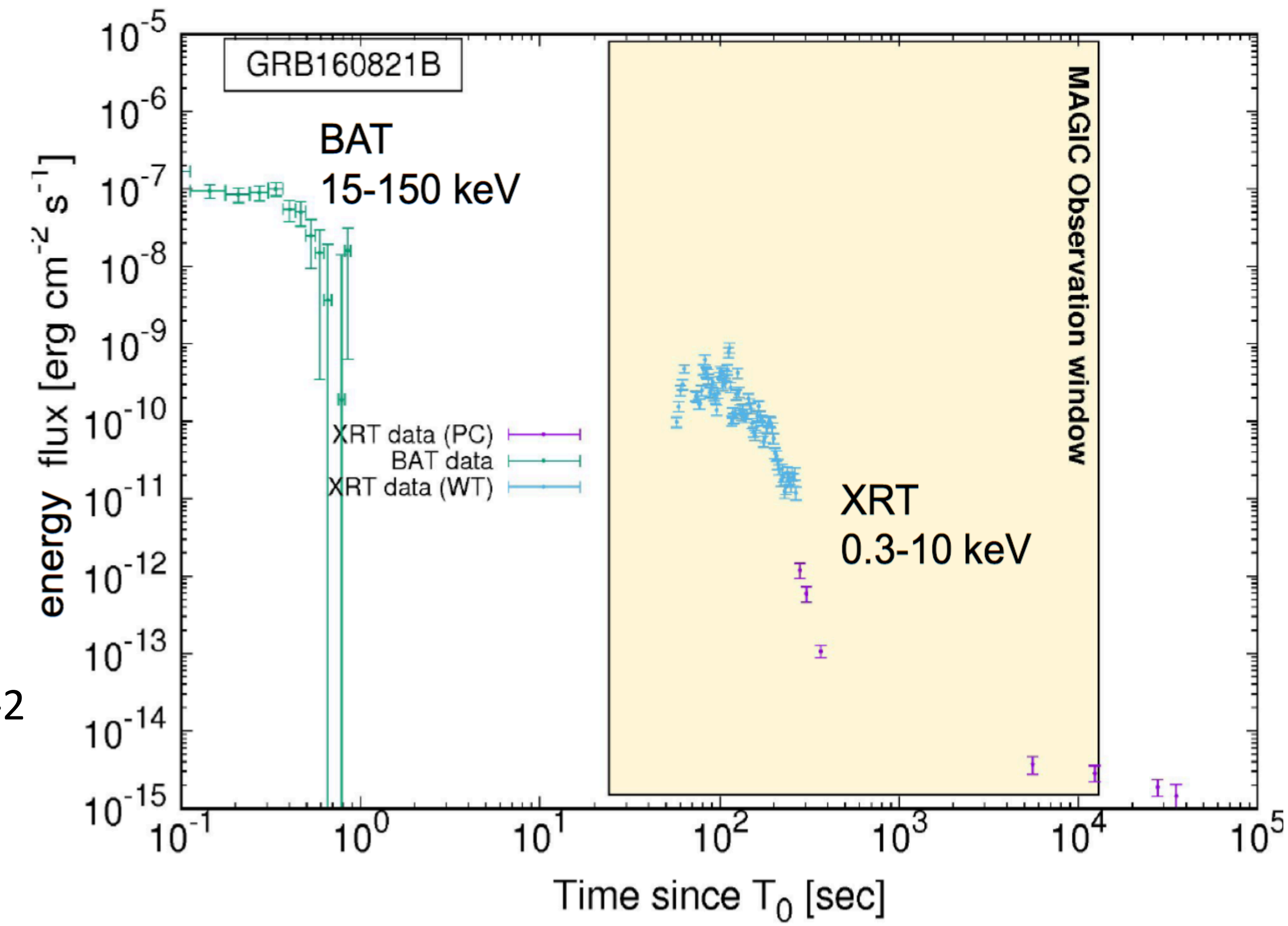


- 101 (as of May 2018, not all analyzed), 23 started < T_0+100 s, 15 stereo
  - fastest 3: **24 s** (**160821B**), 26 s (in 2013, z=1.30), 29 s (in 2015, z=2.59)
    2 more stereo of z<1.5: 55 s (in 2014, z=1.32), 60 s (in 2013, z=1.16)
- 2 stereo with z<0.5: **160821B (z=0.16)**, 160623A (z=0.37, T_0+7.6e4 s)

Short GRB 160821B

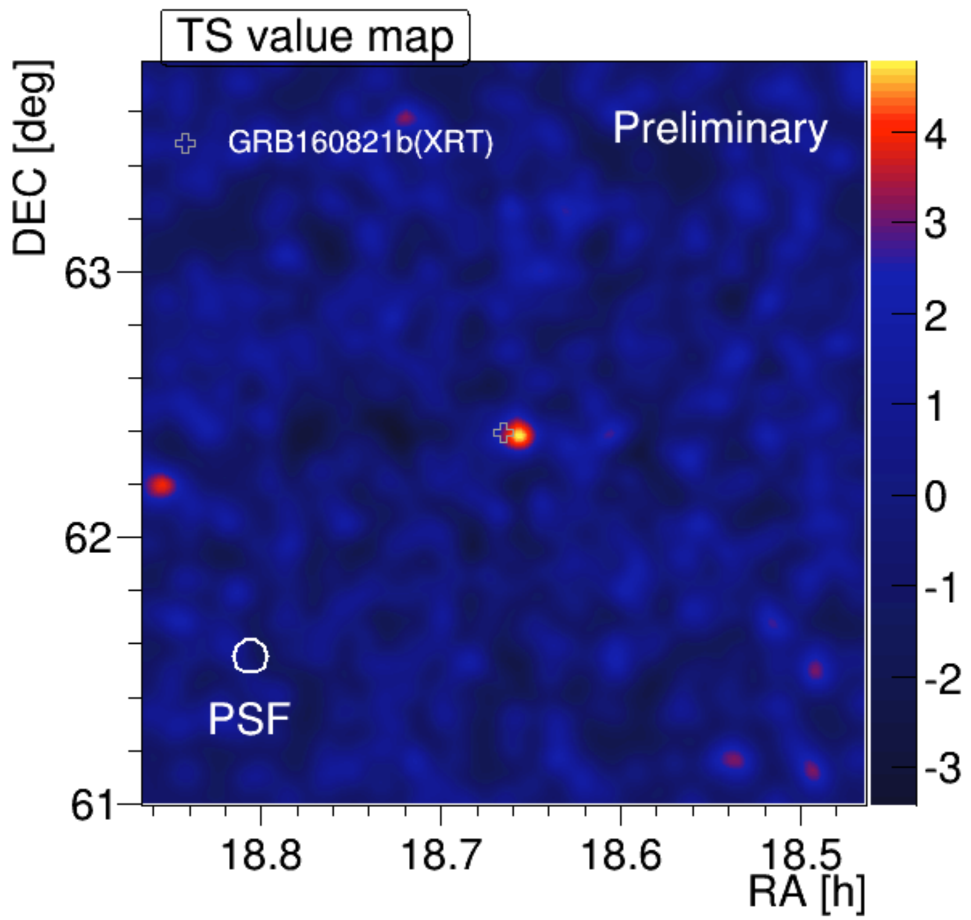
(ICRC 2017, Texas Symposium, etc., MAGIC Coll. in prep. (2018))

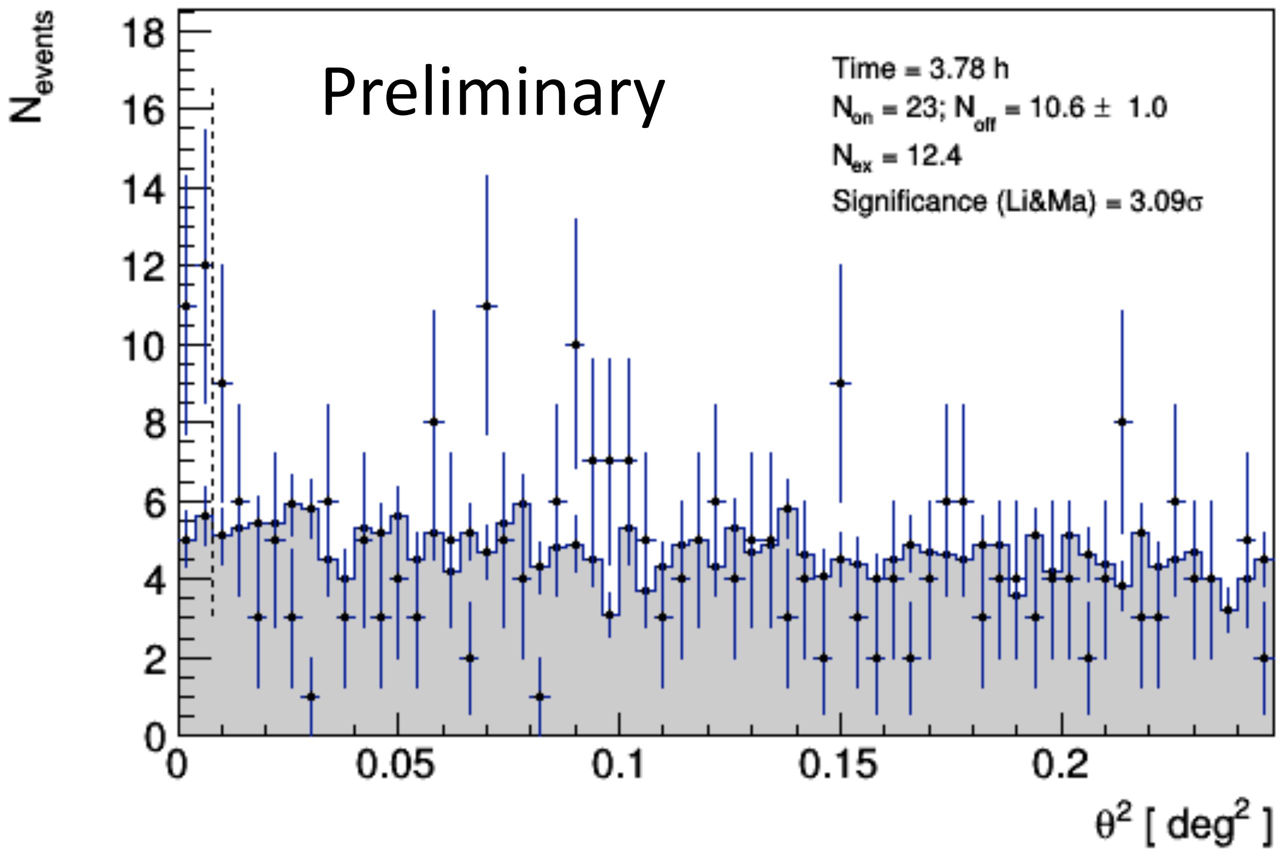
- ***Swift-BAT*** detected. T90 ~0.5 s
- ***Swift-XRT***:
  t < 300 s extended emission +
  steep decay, t < 30 ks plateau?
- **<u>MAGIC</u>** <u>covered this period</u>
  24 s - 4 hr (14.4 ks)
- ***Fermi-GBM***:
  T90 ~1 s, Ep ~= 84 keV
  S(10-1000 keV) =1.7e-6 erg cm^{-2}
  Eiso =1.2e50 erg (with z=0.16)



- ***Fermi-LAT***: no detection
- **Optical** (NOT, WHT (z=0.16), GTC, MASTER, Swift-UVOT), **Radio** (VLA, AMI)
- **IR** (HST) : constraints on *<u>kilonova. Hint in H-band?</u>* (Tanvir et al. in prep)

Signal from MAGIC

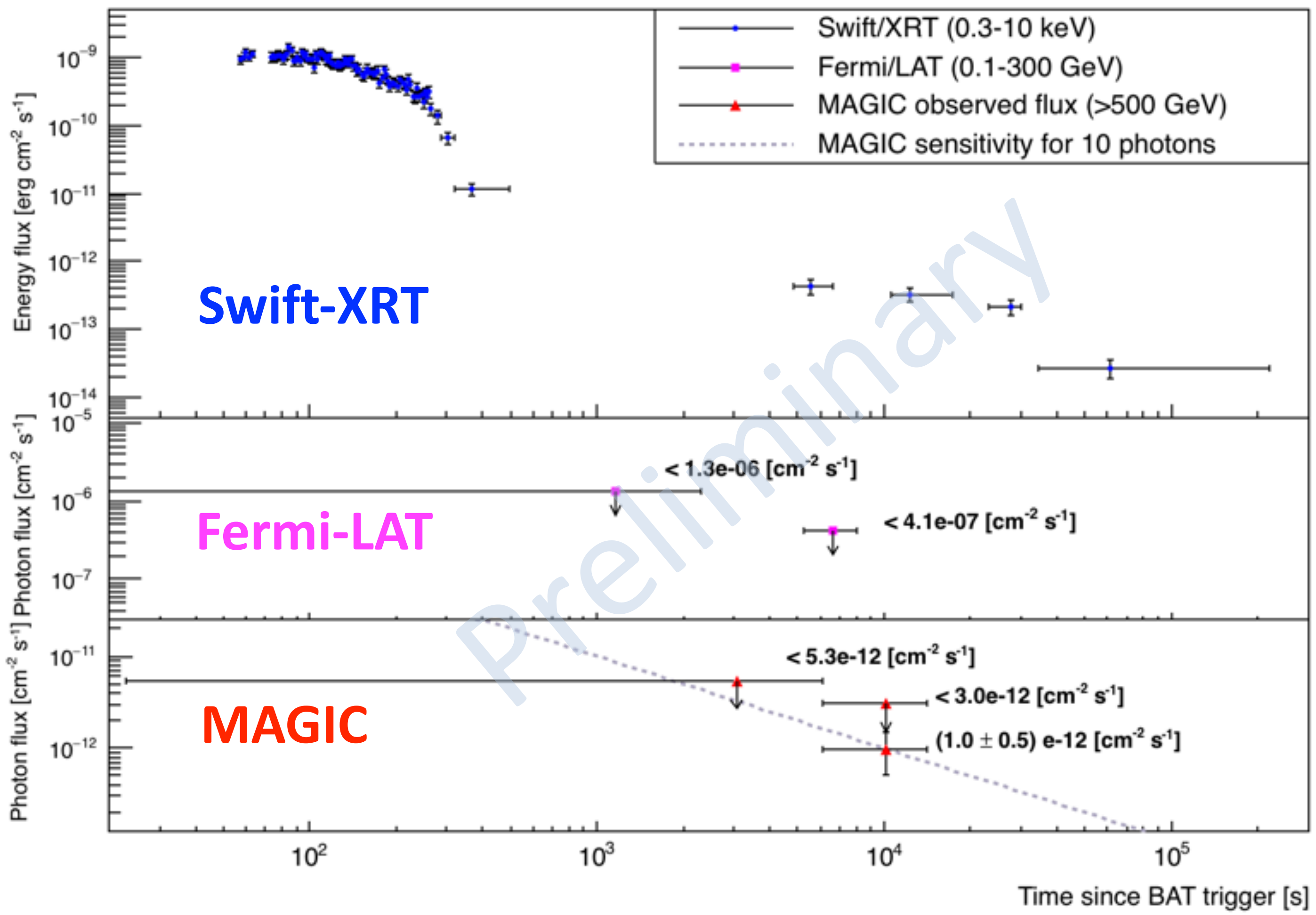


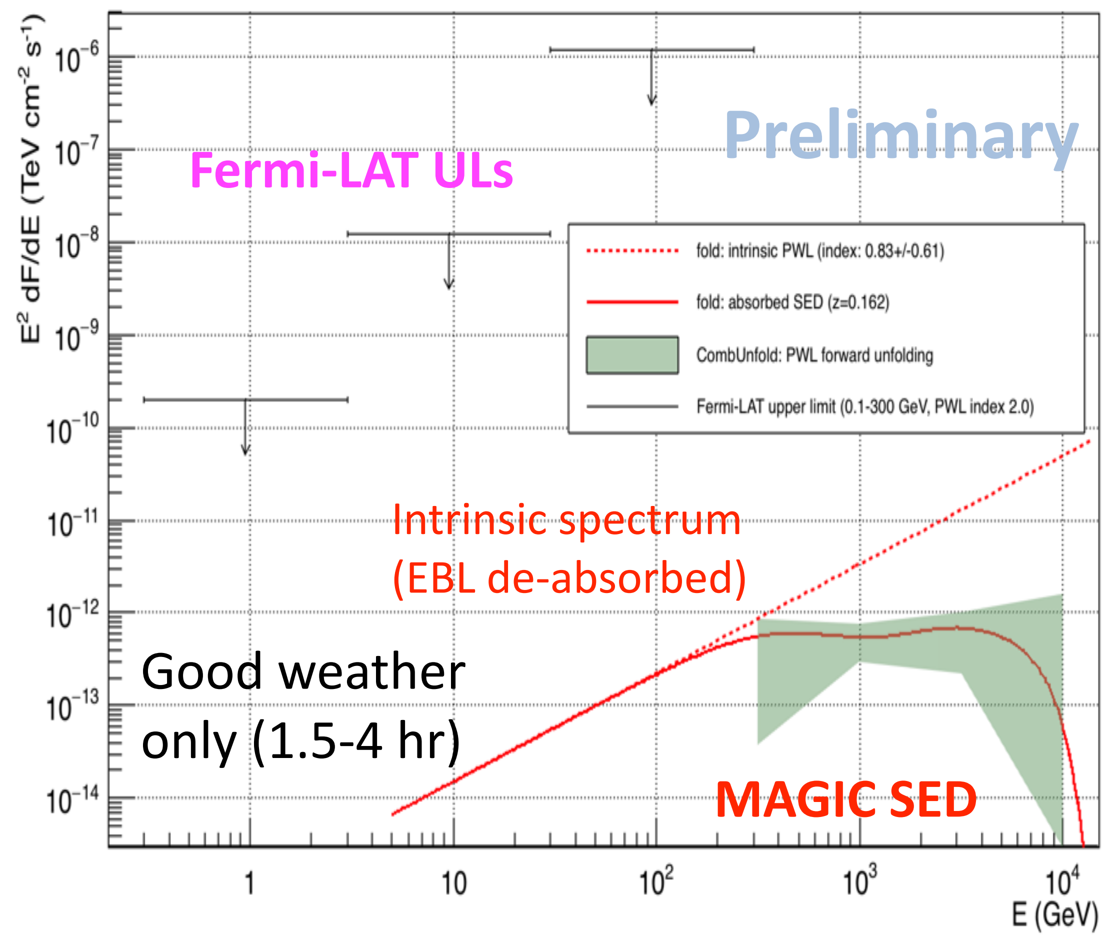


- Bright moon (dedicated analysis needed), adverse weather up to 1.5 hr
- 4 hr data: >4 sigma (pre-trial), **3.1 sigma (post-trial) in >600-800 GeV** Not firm detection (requiring >5 sigma post-trial). **A hint of a detection**.
- No (apparently) interesting source around
- Observed ~1 yr later but nothing found. No unknown steady source

Lightcurve & SED

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes





- MAGIC & LAT points **compatible with a relatively flat LC** coinciding with a possible X-ray shallow decay (though not constraining much)
- **Suggested flat SED** is OK with the EBL attenuation. Intrinsic spectrum is relatively hard (PWL with index 0.8 +/- 0.6). Beyond synchrotron?

Lightcurve models

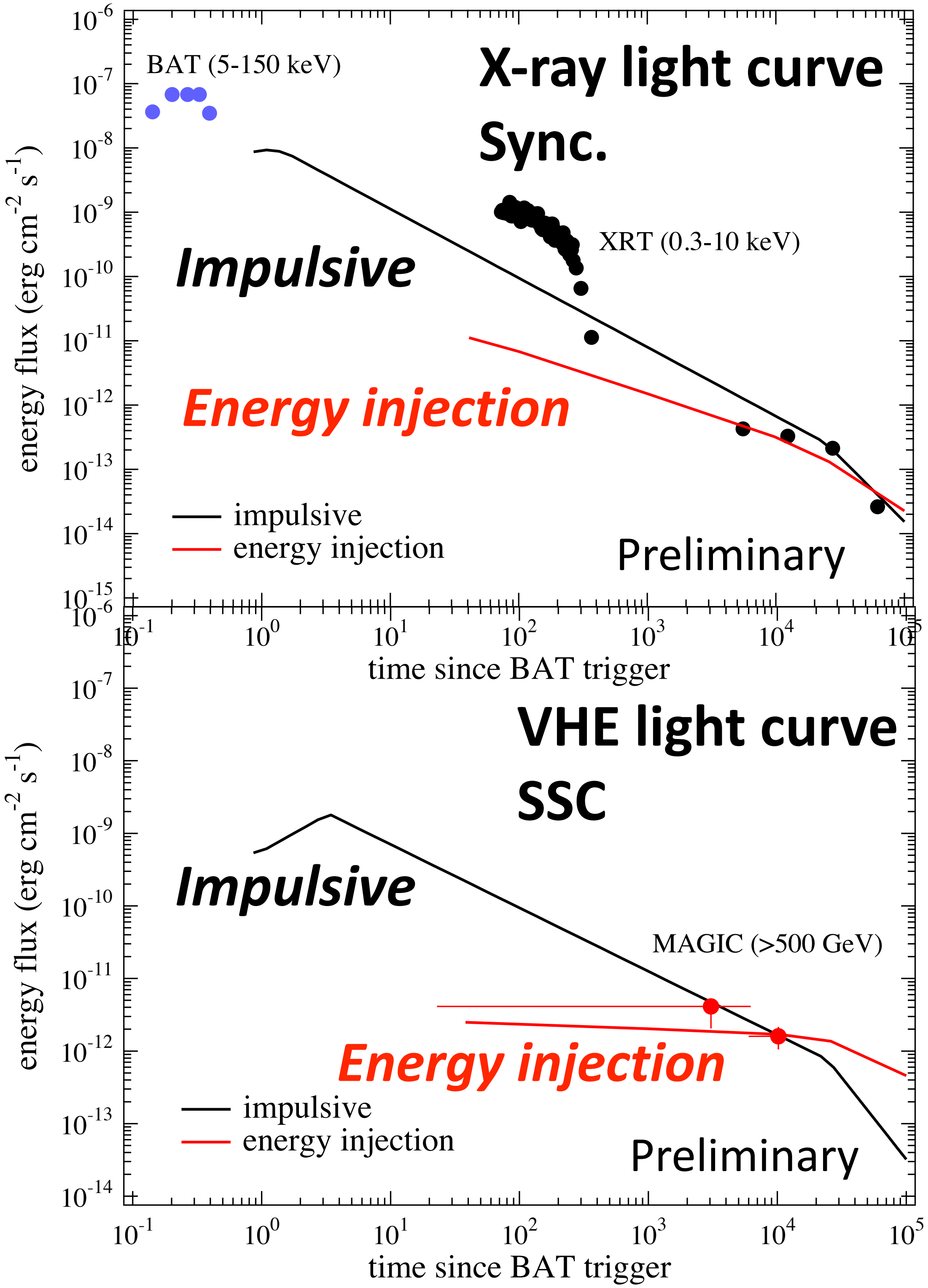
By S. Inoue. MAGIC Coll. in prep (2018)

- **Implsive**:
  single pulse injection with single Γ
  Not too bad, but marginal with VHE UL.
  Not nice in X-ray (? Jin et al. 2017)

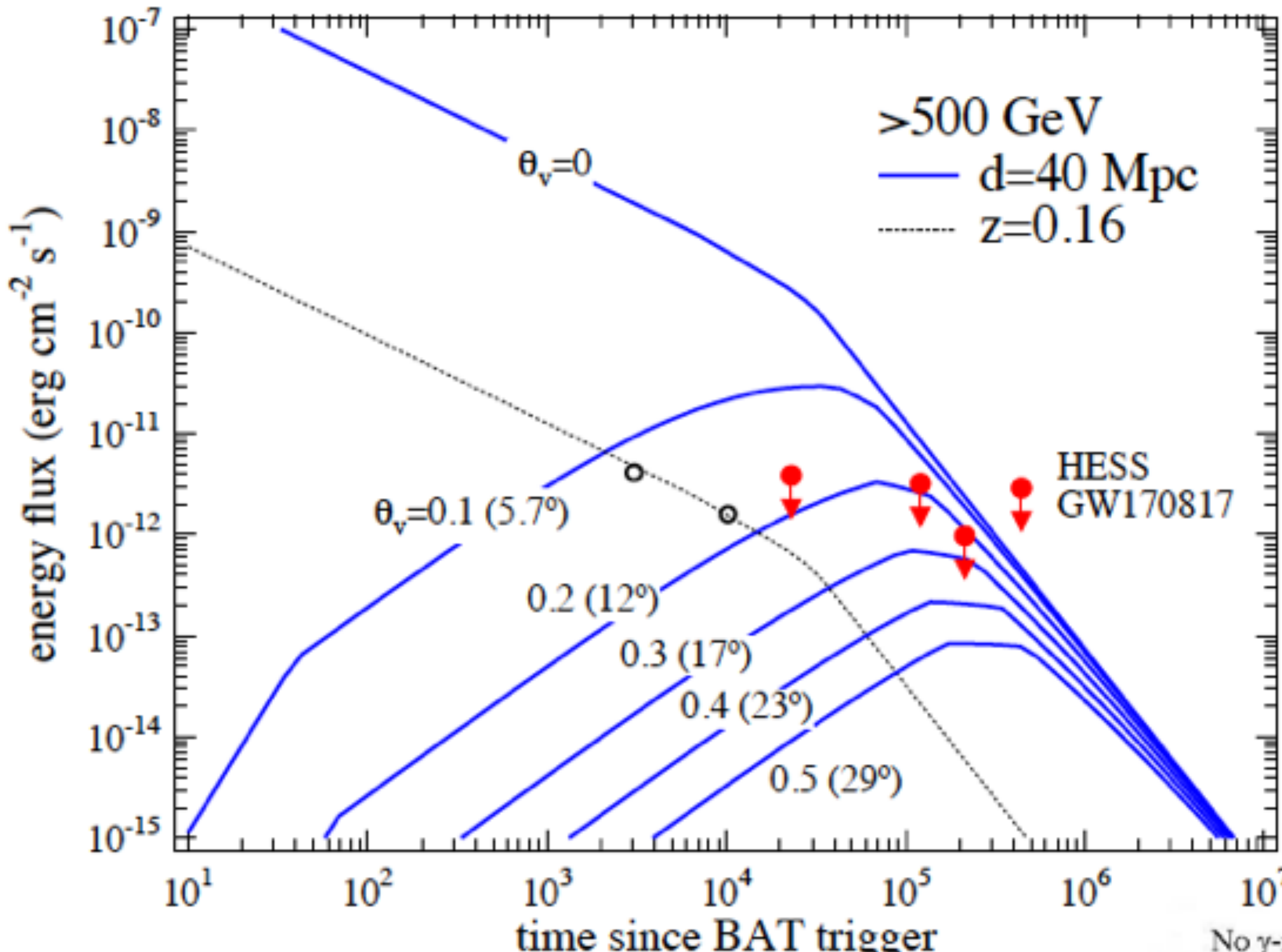
- **Energy injection**: “Refreshed shock” (Sari & Meszaros 01, Veres & Meszaros 14)
  Additional injection after the main, with multiple Γ
  Slightly better both in VHE and in X, but inconclusive

- Anyway, need another explanation for the X-ray extended emission.
  Transient ms pulsar?

- Both models work also for SED (backup)

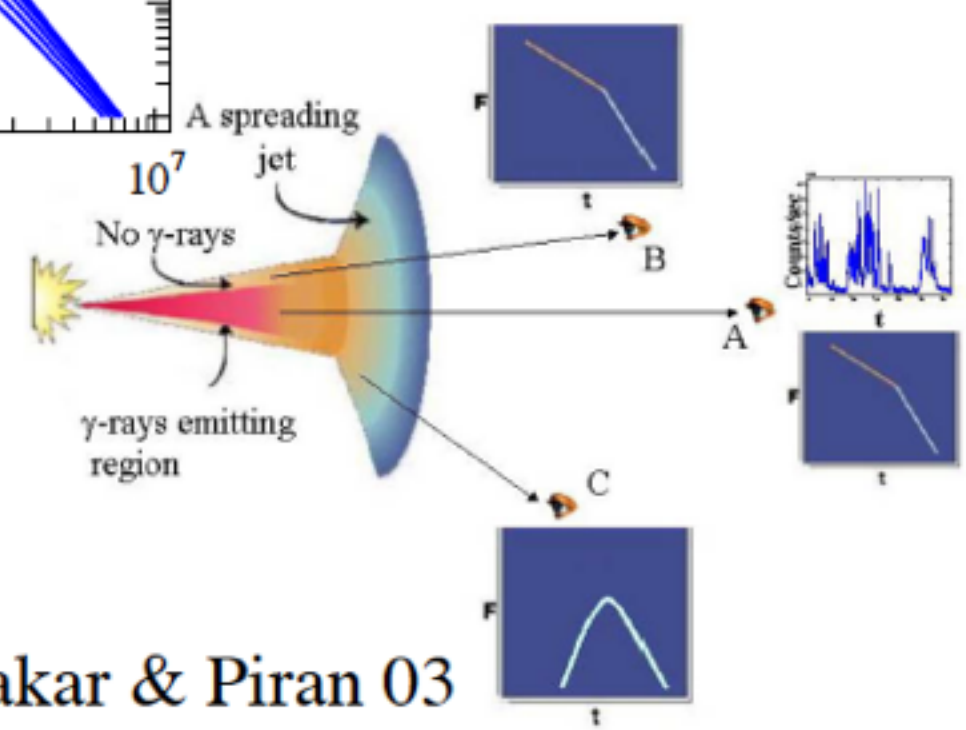


off-axis afterglow: VHE counterpart of NS mergers?



By S. Inoue.
MAGIC Coll. in prep (2018)

c.f. Granot+ 02
pt. source approximation



Nakar & Piran 03

Standard picture (impulsive injection) + off-axis angle still gives us an interesting implications for GW follow-up observations!

More MAGIC GRB papers to come

- Stack (?) ULs of stereo GRBs (2013~): draft in prep
- LAT GRBs in 2016-2017: analyses mostly ready
- Some more recent interesting GRBs: data taken

Anyway,,, stay tuned!

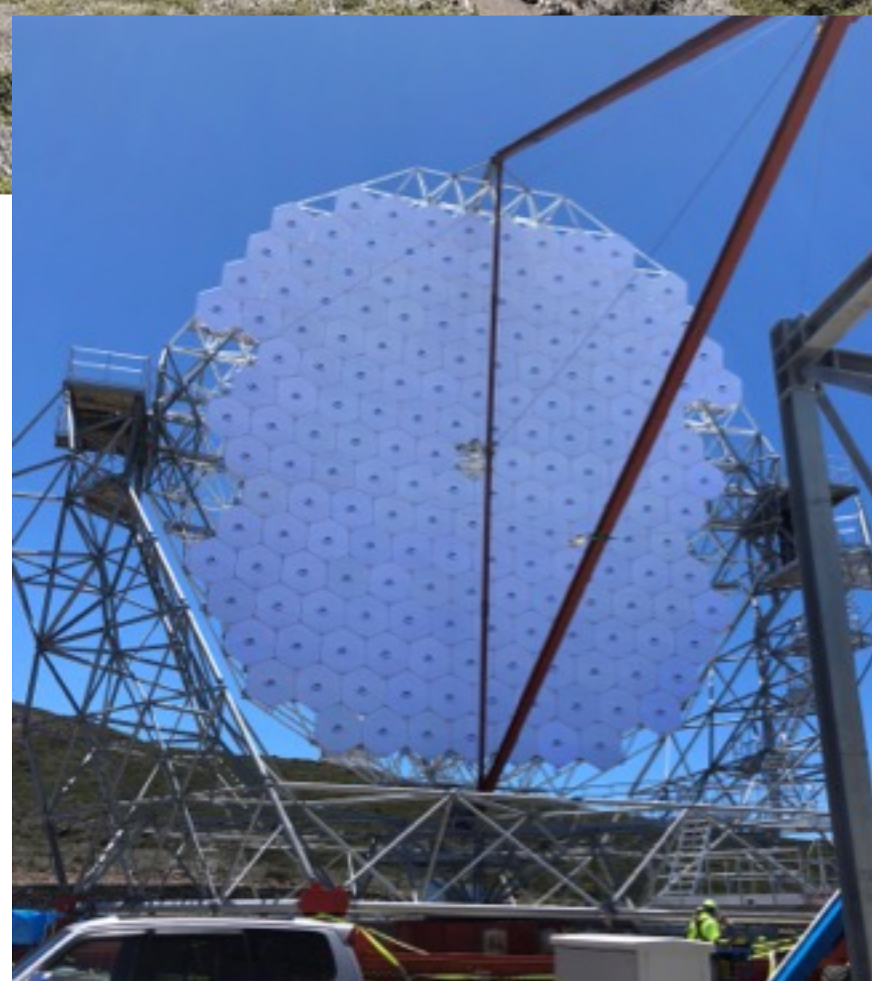
and more to come,,,

next to the stable MAGIC telescopes,,,

CTA LST will come soon

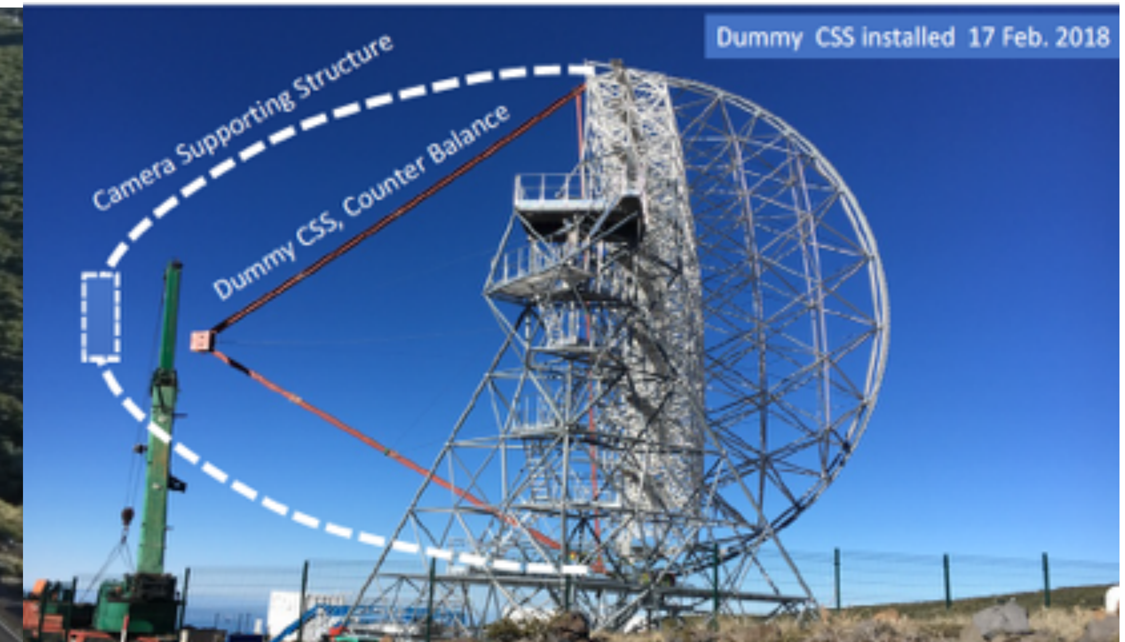
In reality now

11 May 2018



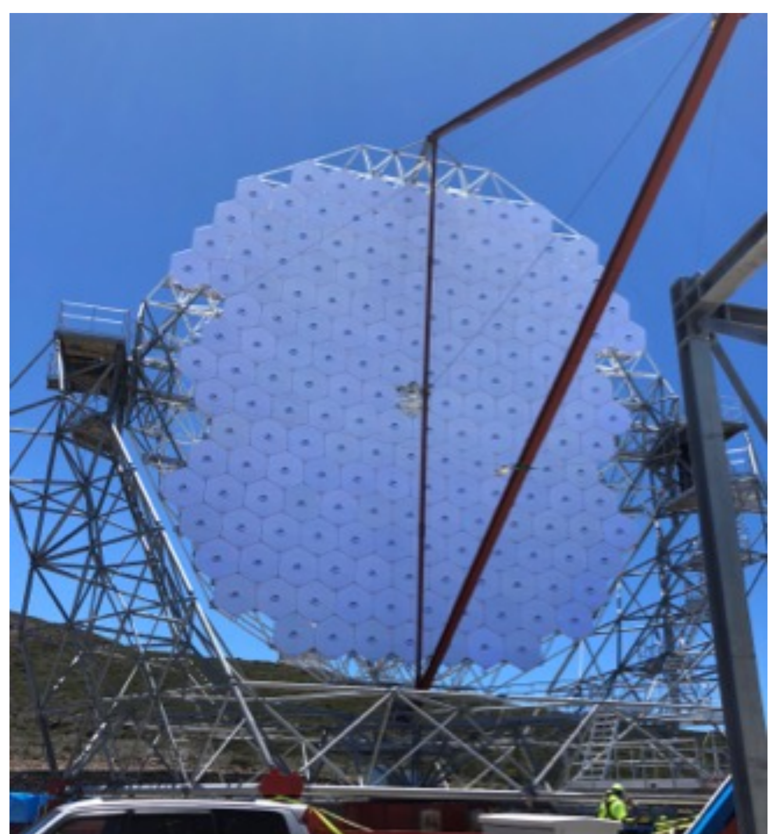
23 May 2018
181 mirrors
installed!

Mechanics status



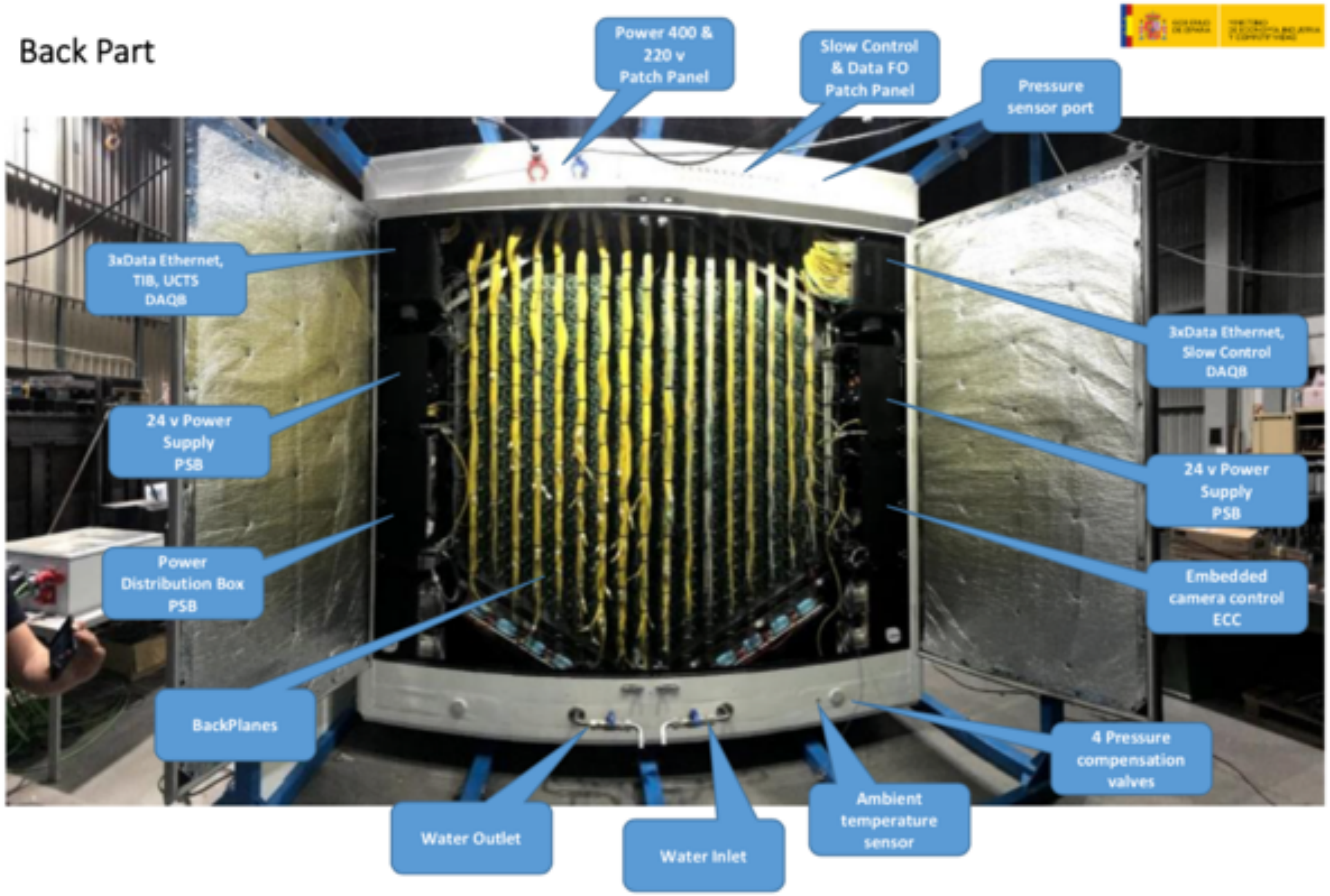
CSS & Camera access in June

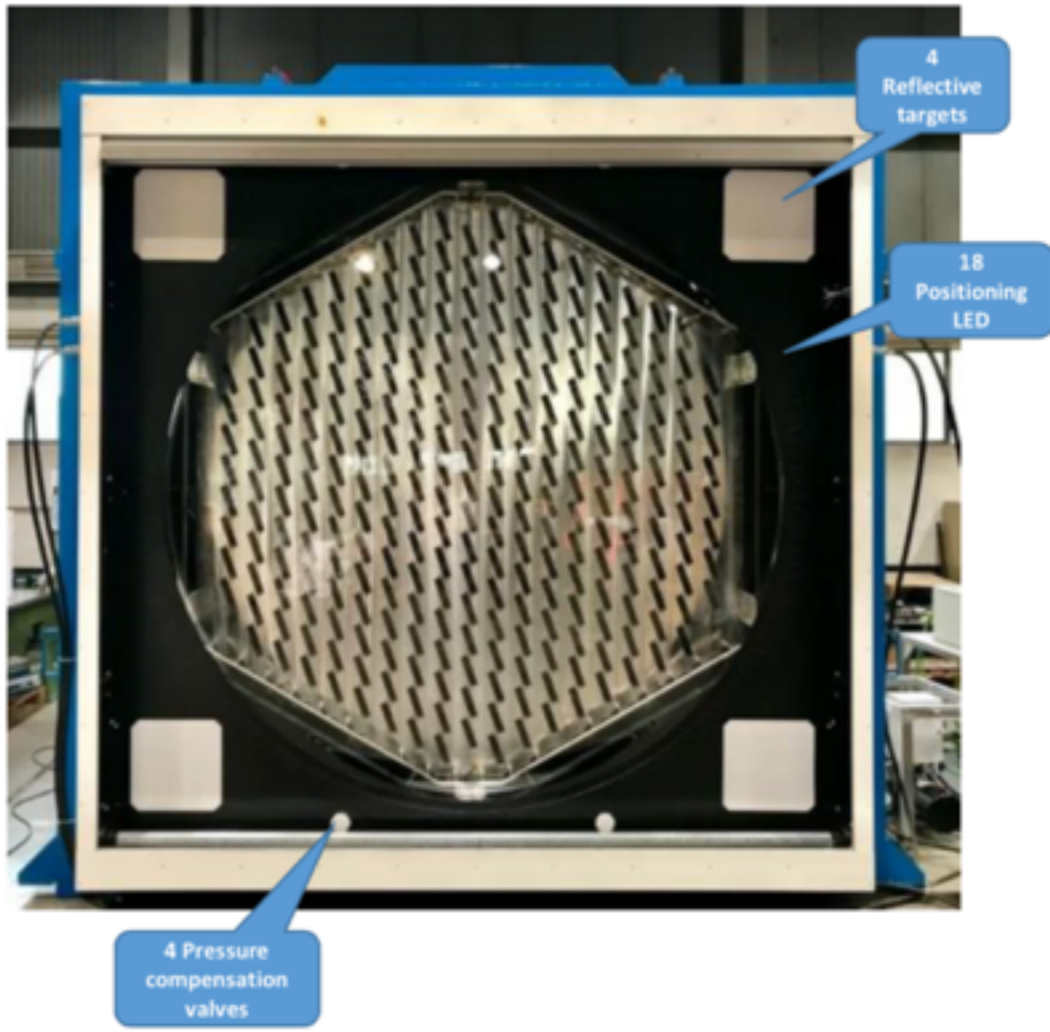
Optics status



- 181 mirrors already installed, 17 more in Jul
- **Mirror adjustment** (Active Mirror Control) being prepared, **to be installed in Aug**

Camera status

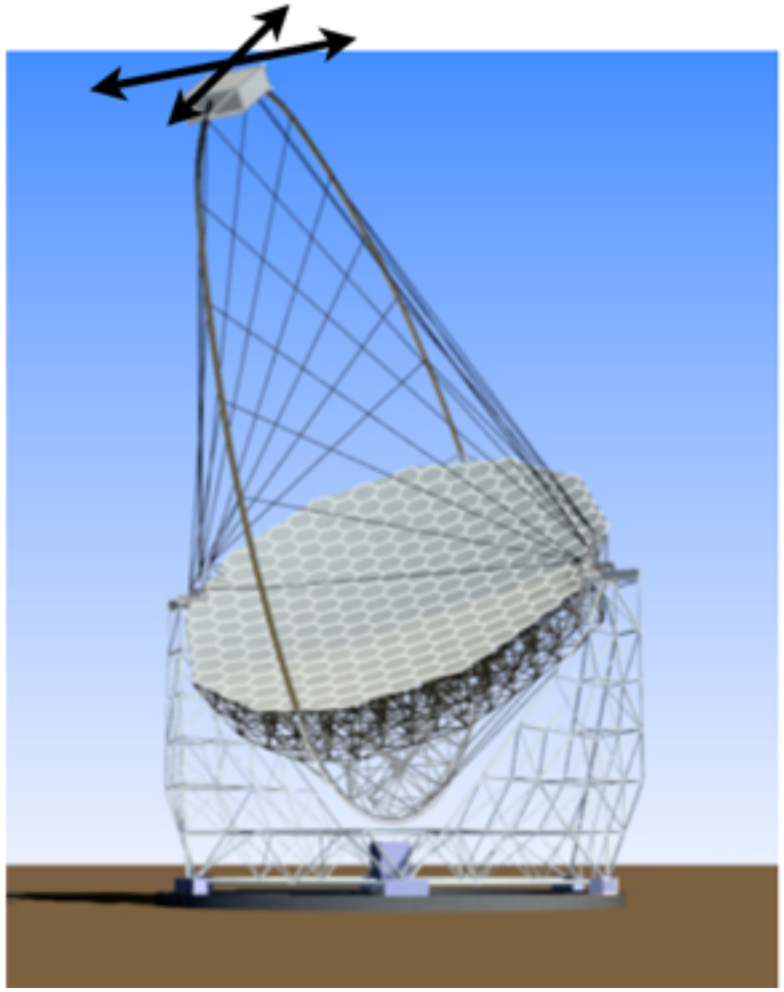


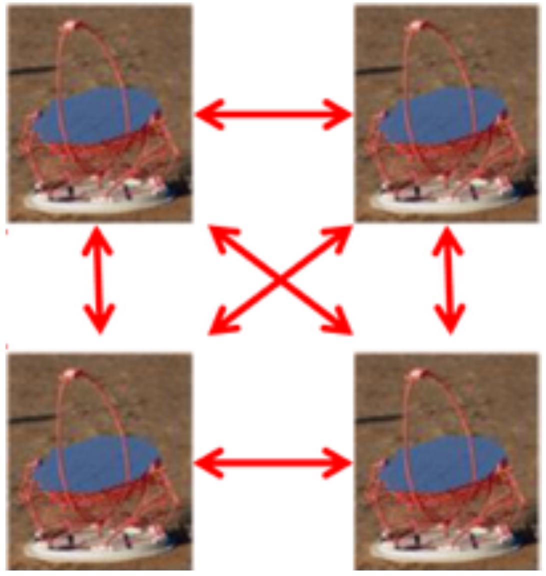


- Moved from CIEMAT (Madrid) to IFAE (Barcelona) for assembly.
- ~ half of PMT modules installed.
- Final assembly of the light guides in Aug. **Installation in Sep.**

LST features for GRBs

- **Fast movement (180 deg / 20 s)**
  - **Improved telescope motor drive**
    less oscillation during/after slewing
  - **Additional pointing monitor**
    correct for remained fast oscillations
  - **Active Mirror Control (AMC)**
    dynamic mirror alignment for a short duration performance
- **Low energy threshold (>20 GeV)**
  - **Built-in analog sum trigger**
    (Not yet standard in MAGIC GRB obs.)
  - **Trigger exchange ('OR') among LSTs**





DAQ, analysis, MC,,,: CTA North IT center

cta cherenkov telescope array

- We should and will focus more on data-related devs (DAQ, analyses, MC), to achieve physics results

CTA-N IT center procured by Japan

2000 cores
3 PBytes

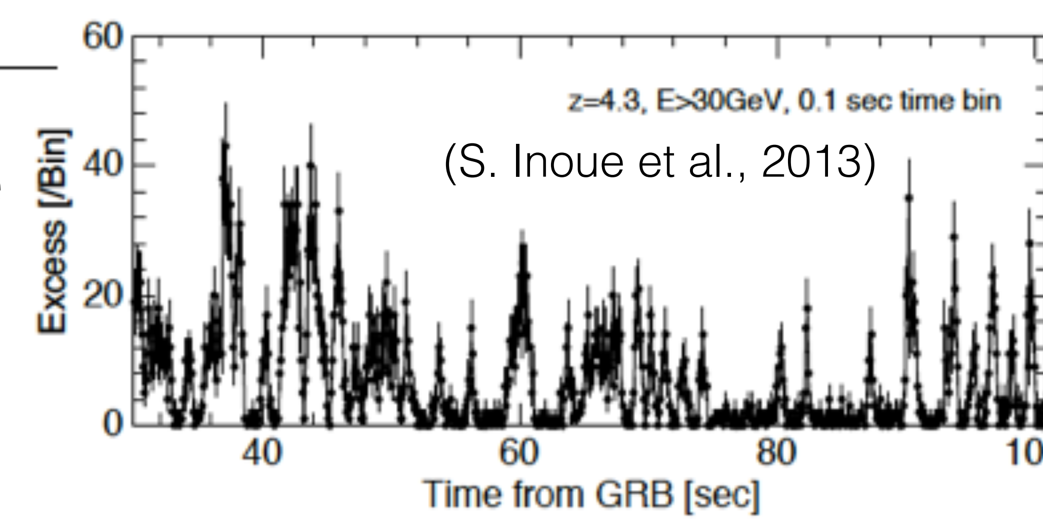
Discussions led by ICRR members

Performance for GRBs/transients

- ~1 prompt obs. / month

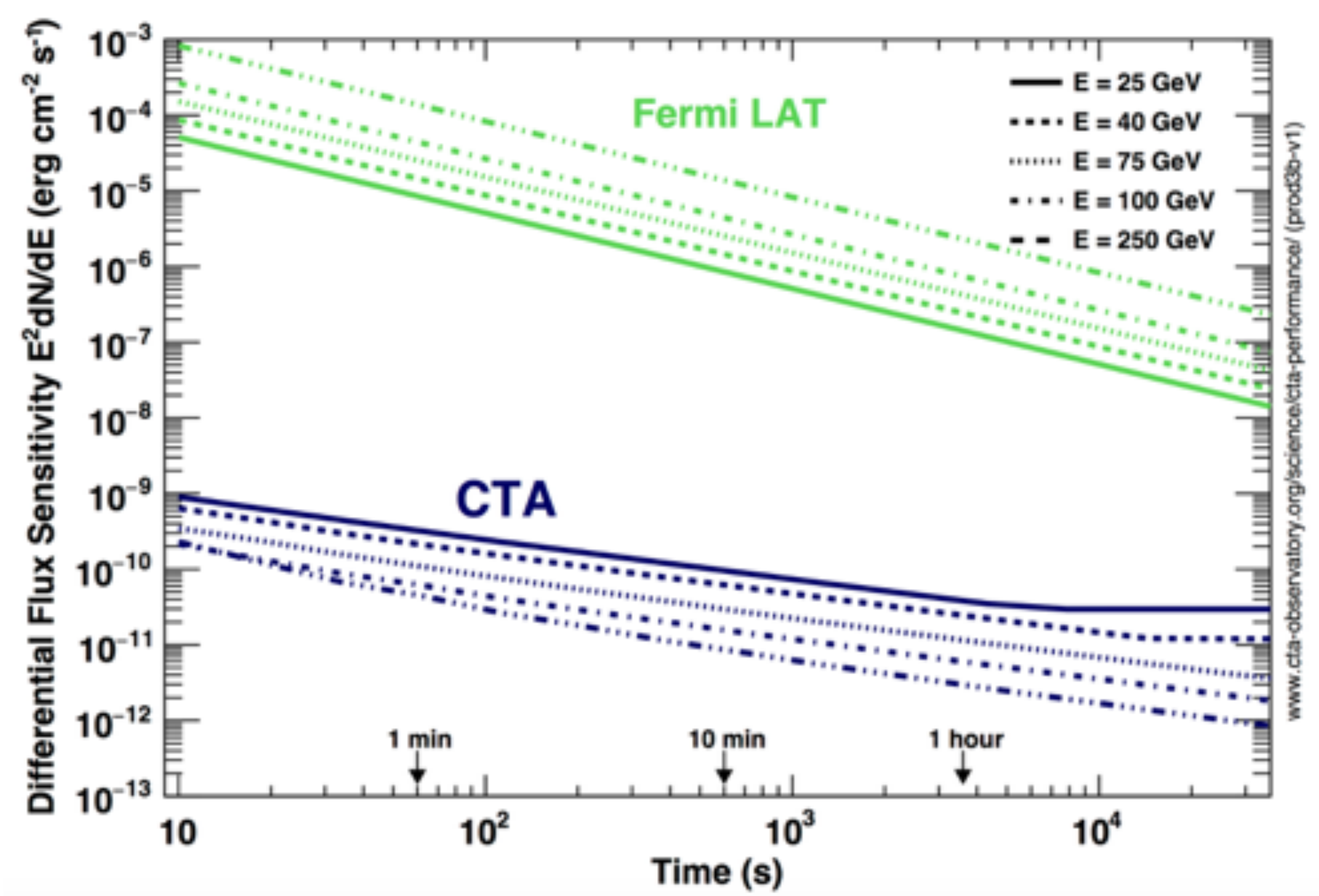
Strategy	Expected event rate (yr^{-1})	Exposure per follow-up (h)	Exposure per year ($h\,yr^{-1}$)
Prompt follow-up of accessible alerts	~12	2	25
Extended follow-up for detections	0.5–1.5	10–15	10–15
Late-time follow-up of HE GRBs not accessible promptly	~1	10	10

"Science with the Cherenkov Telescope Array", astro-ph:1709.07997

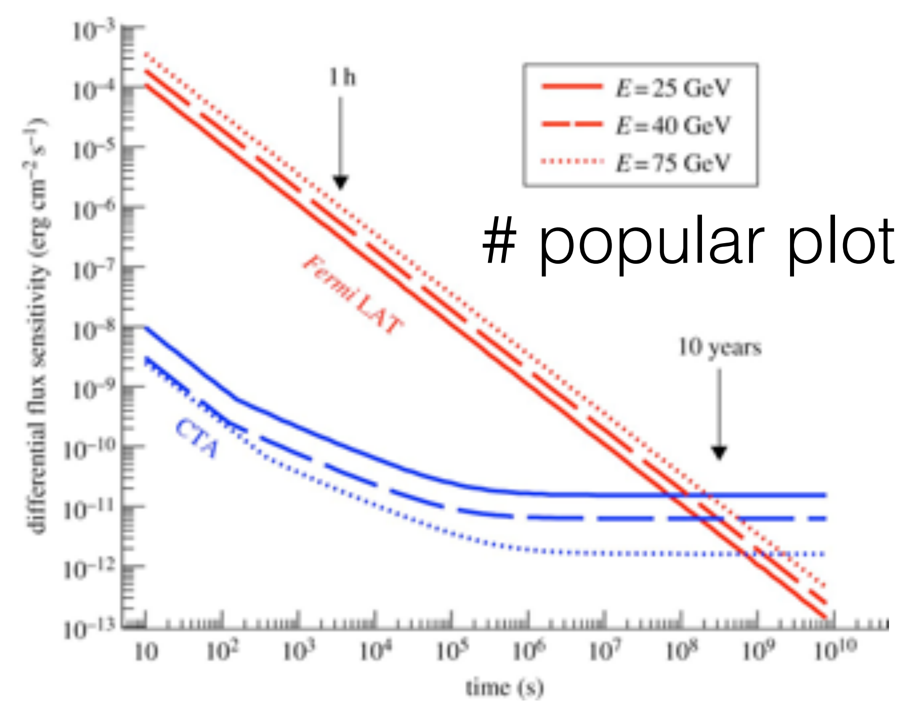


(S. Inoue et al., 2013)

- If observed, much more sensitive



new CTA-official plot



popular plot

Expected GRB physics

cherenkov telescope array

- (First) Firm detections of VHE gammas from GRBs
- Detailed **LC** of gammas, together with X-ray satellites.
  time correlation => implication to mechanism
- If together both with X-rays and GeV (Fermi-LAT):
  spectrum extended to VHE? 2nd component?
  => understanding of the mechanism (Sync vs. IC)

Triggers by Swift-BAT (or similar satellites) & Fermi-LAT obs needed: we should hurry up

- Short nearby GRBs: together with GW signals?
  => confirmation of (one of) the origins

Better GW localization: we need KAGRA

Summary

- Even with IACTs like MAGIC, still a lot left for GRB physics
- SGRB 160821B: detection hint, but interpretation inconclusive
- CTA LST will start to understand its mechanism and origins

Inauguration of LST-1 on 10 Oct 2018 !!!

Backup

Abstract

- Gamma-Ray Bursts (GRBs) are the most luminous objects in the Universe. Their origins are considered to be a collapsing death of a massive star, or a neutron star merging with another neutron star or with a blackhole. However, the physical processes happening in the objects are not yet revealed well. A long-awaited detection by Cherenkov telescopes will be a key ingredient to elucidate the GRB emission mechanism. In this seminar, observations of GRBs with MAGIC telescopes are reviewed, and the expected physics cases with Large Size Telescopes of Cherenkov Telescope Array project are introduced.

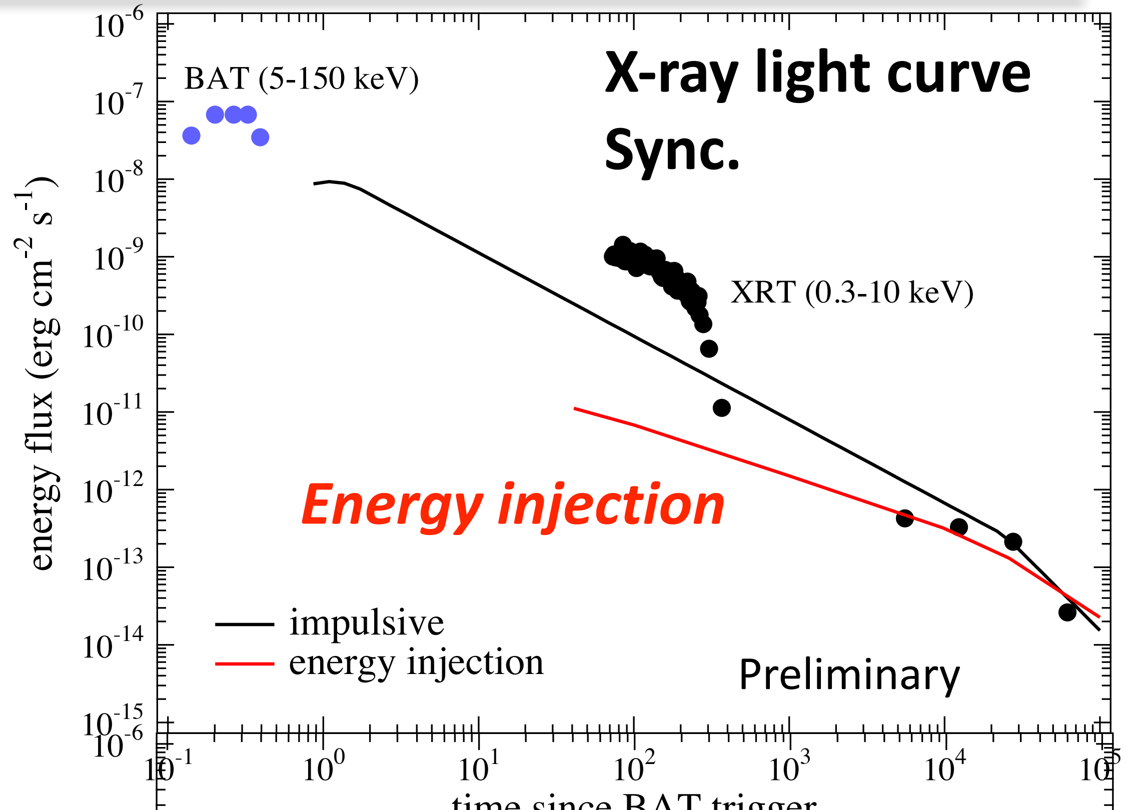
If the light curves are flat

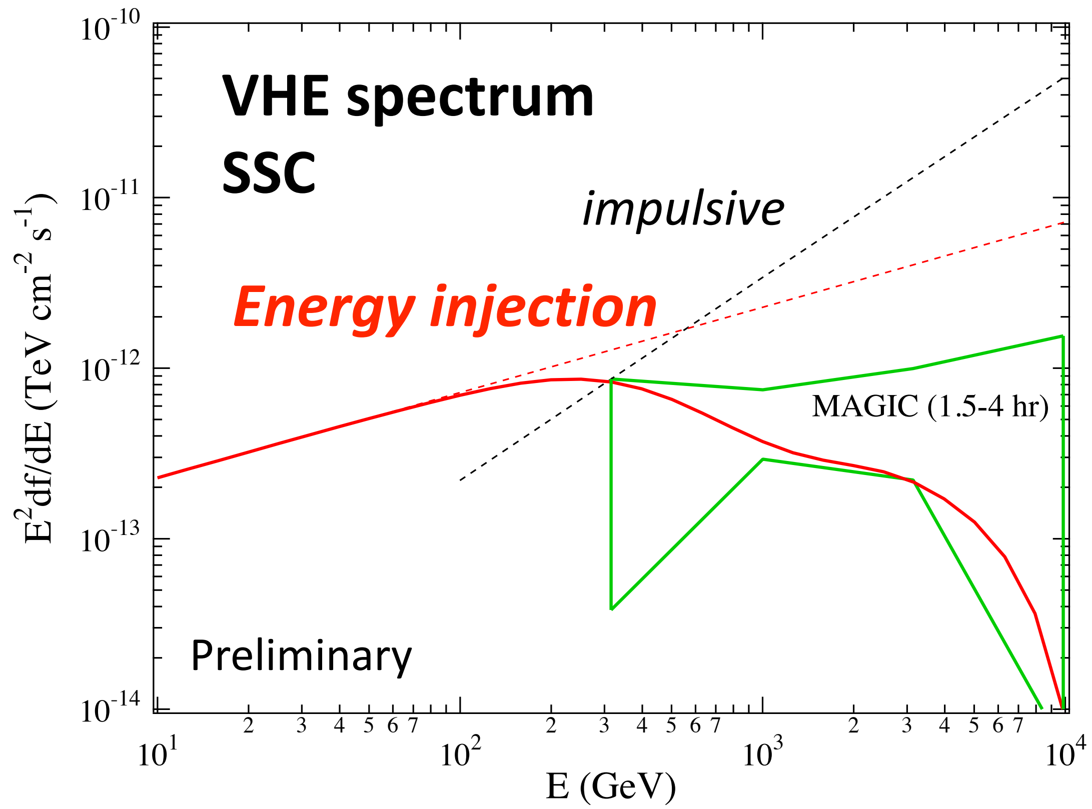
Based on “refreshed shock” scenario

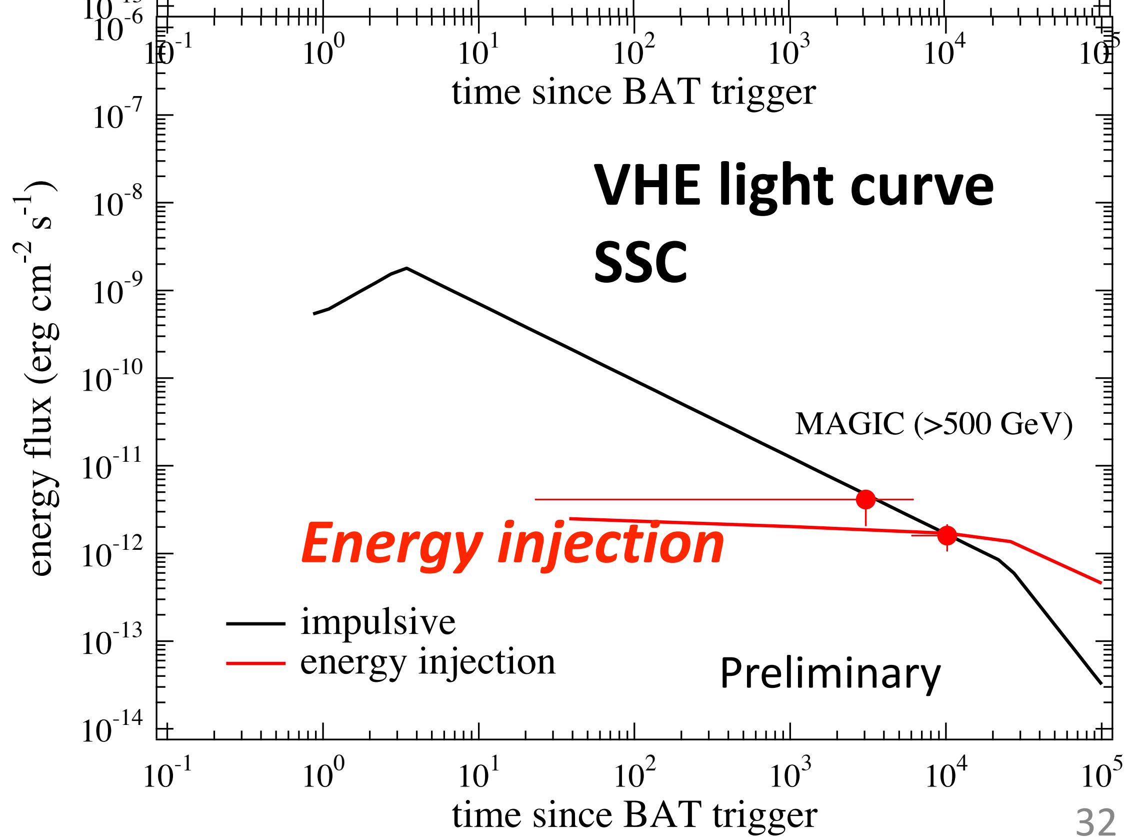
(Sari & Meszaros 01, Veres & Meszaros 14)

blastwave with additional energy injection

- Extended emission by transient ms pulsar
- Collapse to BH, outflow with multiple Γ
- model SED is compatible with MAGIC (but impulsive model as well)







- impulsive
  - uniform ISM
  - Ekin=1051 erg, n=0.1 cm-3
  - εe=0.1, εB=0.01, p=2.1, θj=0.1
  - EBL Dominguez+ 11