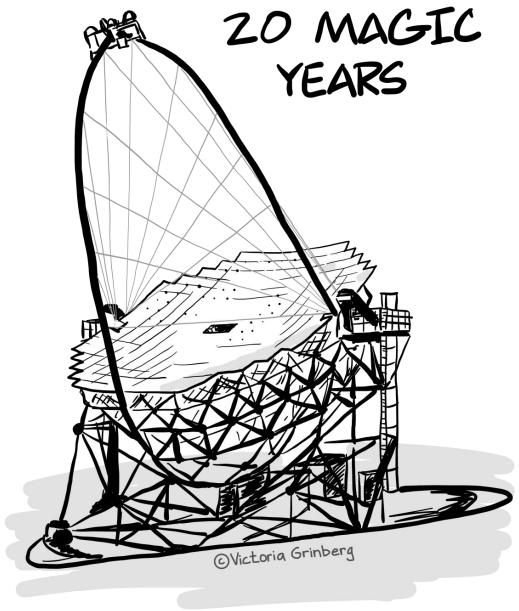
MAGIC

Major Atmospheric Gamma Imaging Cerenkov Telescopes



Gamma-ray bursts with MAGIC

Alessio Berti
Max Planck Insitute for Physics

MAGIC 20th Anniversary

Why MAGIC?

The MAGIC telescopes have...

- fast repositioning --> 7deg/s in “GRB mode”
- lightweight structure --> ~64t for each telescope
- high sensitivity --> 5sigma with ~20% of the Crab Nebula flux in 20min above ~100GeV
- low energy threshold --> ~50GeV with standard trigger

Designed to catch GRBs!

Status of GRBs with IACTs before 2019

- Several attempts, but no detection
  - MAGIC: 2005-2006 GRBs (ApJ 667, 2007), GRB050713A (ApJ 641, 2006), GRB 080430 (A&A 517, 2010), GRB090102 (MNRAS 437, 2014)
  - H.E.S.S. : GRBs observed from 2003 to 2007 (A&A 495, 2009), GRB 060602B (ApJ 690, 2009), GRB 100621A (A&A 565, 2014)
  - VERITAS: follow-up of Swift GRBs (ApJ 743, 2011), GRB 130427A (ApJ 795, 2014), GRB 150323A (ApJ 857, 2018)
  - Whipple: GRB follow-up (ApJ 655, 2007)
  - HEGRA: search for GRB TeV counterparts (arXiv:astro-ph/9611044v1)

Only upper limits... :(

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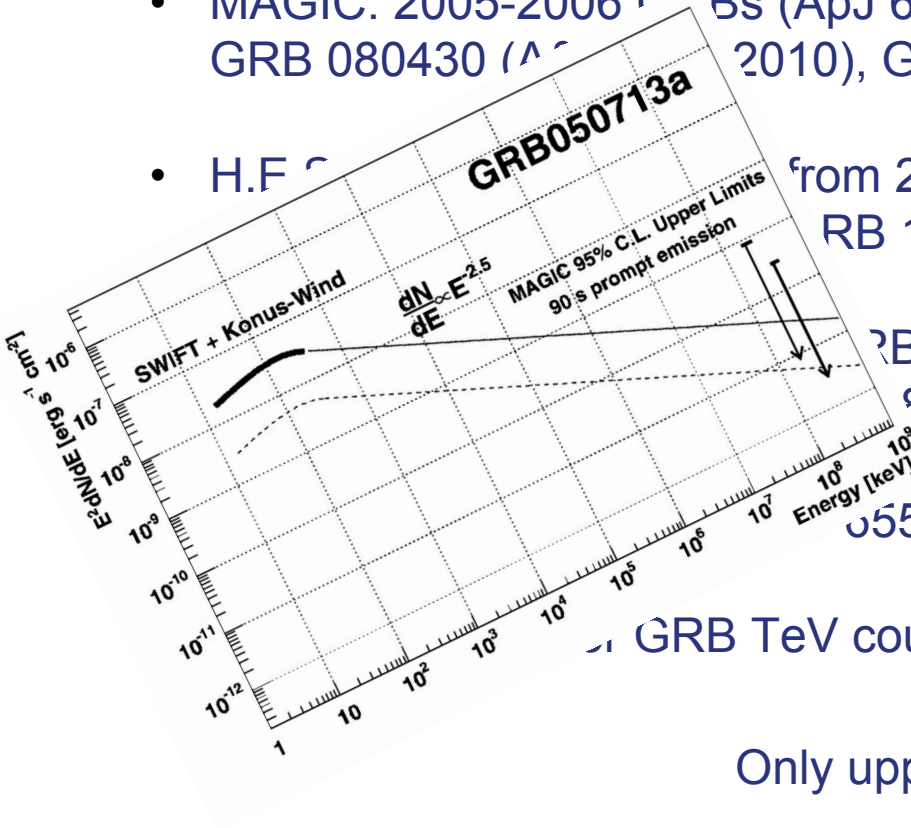
  - RBs (ApJ 743, 2011), GRB 130427A (ApJ 857, 2018)
  - 555, 2007)
  - GRB TeV counterparts (arXiv:astro-ph/9611044v1)



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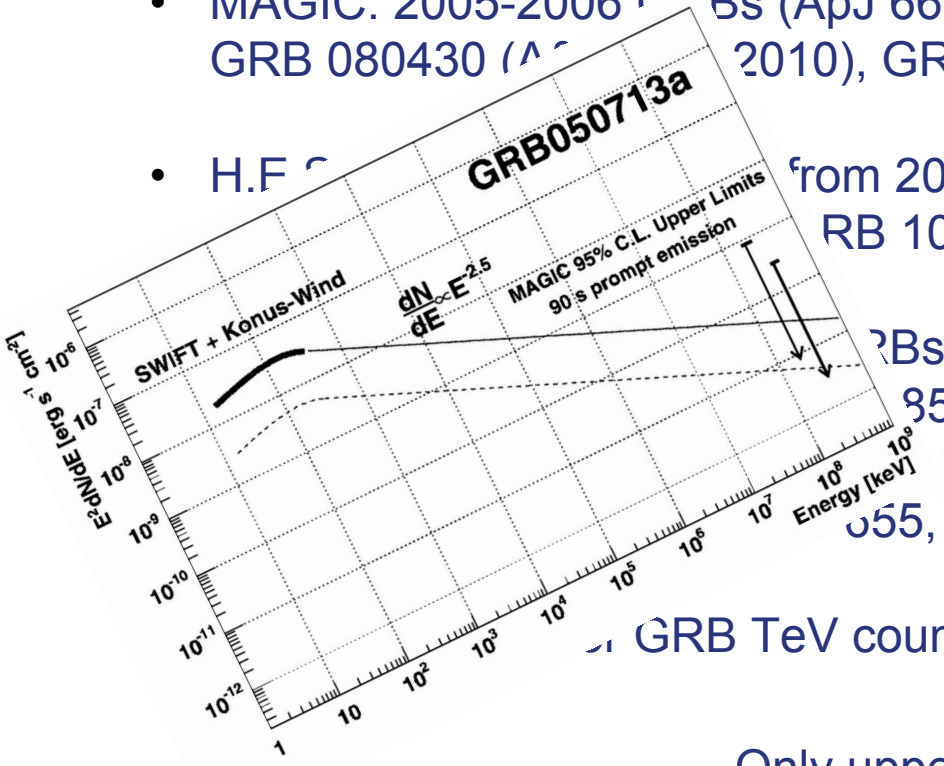
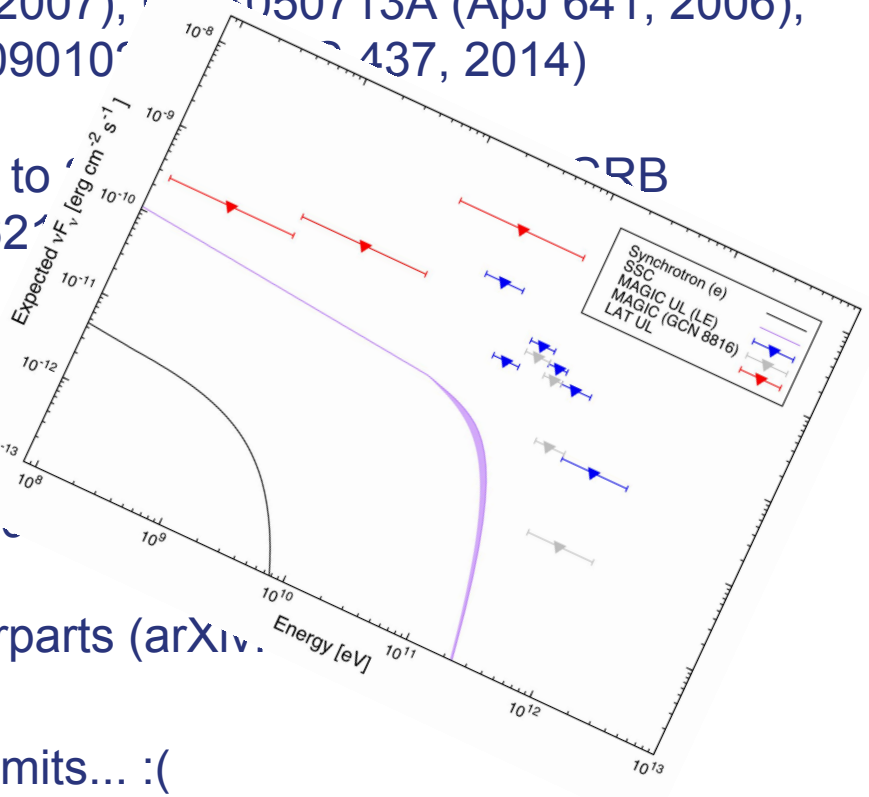
  - H.E from 2003 to GRB
    RB 10062
    RBs (A
    355
    055, 20
    GRB TeV counterparts (arXiv:

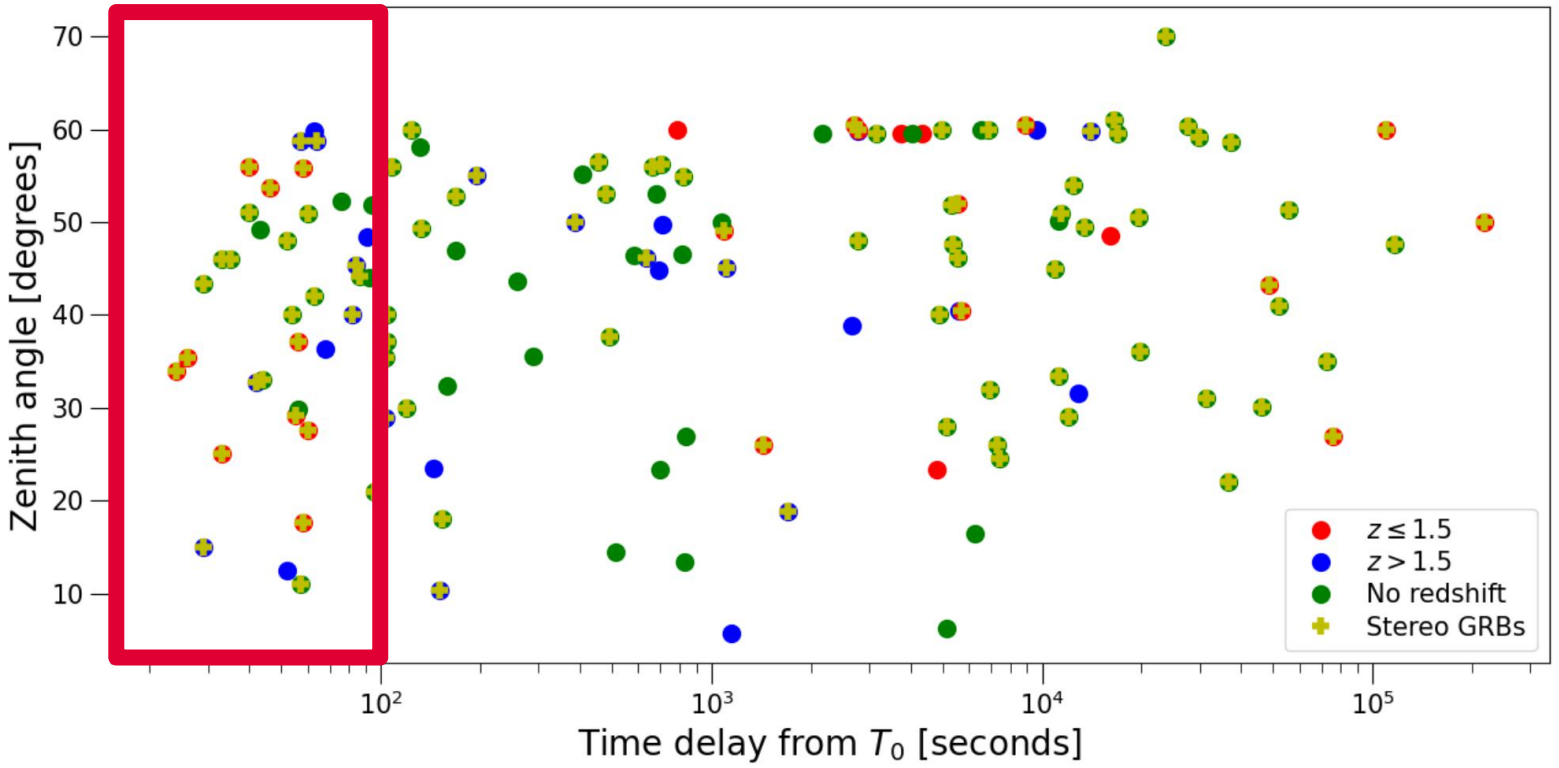




Only upper limits... :(

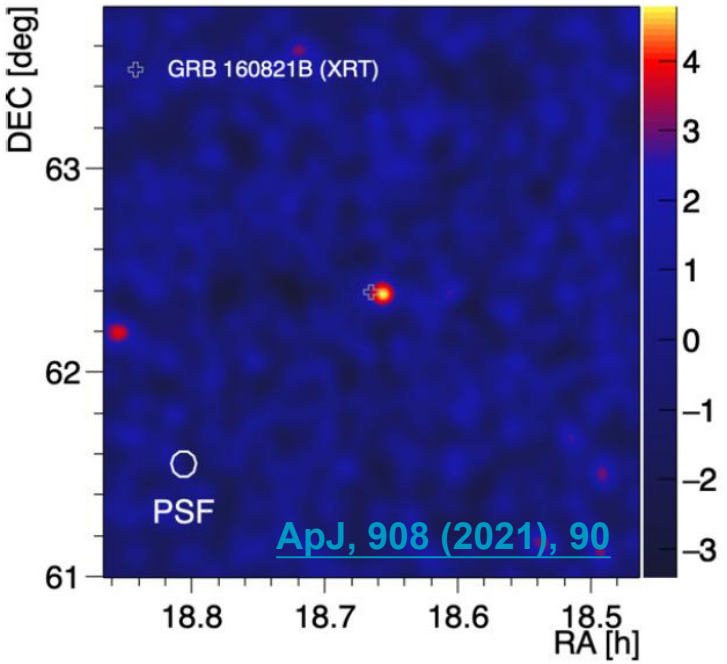
BUT, keep trying: expect the unexpected!!!

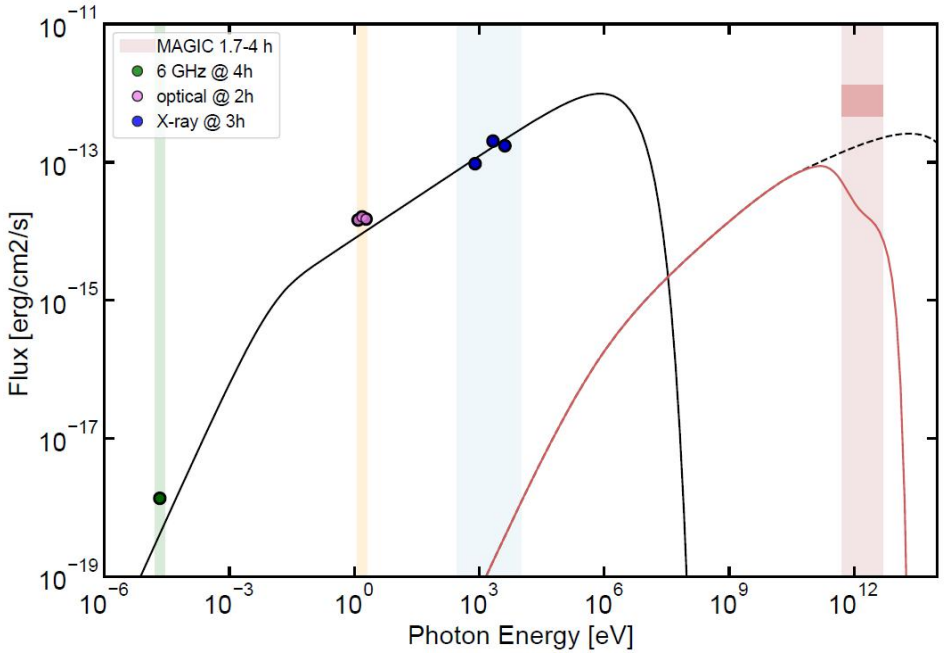
MAGIC GRBs observations



~40 GRBs with delay <100s (red box)
Fastest follow-up: GRB 160821B (24s after T_0)
All GRBs detected by MAGIC or with hints are in the red box (in the early afterglow phase)

GRB 160821B





- Short GRB at low redshift (z=0.16), fast follow-up by MAGIC (24s)
- Data affected by moon and partially by bad weather
- Hint of detection at 3.1 sigma pre-trial, 2.9 post-trial
- Kilonova emission confirmed --> important study in view of GW follow-ups
- Simplest emission model (synchrotron + SSC at external forward shock) is in tension with the TeV predicted flux

A night to remember: 14th January 2019

[magic_priv] You did it MAGIC! we detected a very bright GRB !

Razmik Mirzoyan mirzoyan.razmik@gmail.com tramite www.mppmu.mpg.de
a magic_priv 15 gen 2019, 03:34

inglese > italiano Traduci messaggio

Dear Magicians,

Wake up and enjoy this historical day!

After 15 years of dreaming about the GRB detection, tonight it became reality - MAGIC detected a GRB at a red-shift of 0.42 with > 20 sigma in 20 minutes observation time!

This is the best confirmation for the very best science year of MAGIC (please see the attachments) !

CONGRATULATIONS!!!

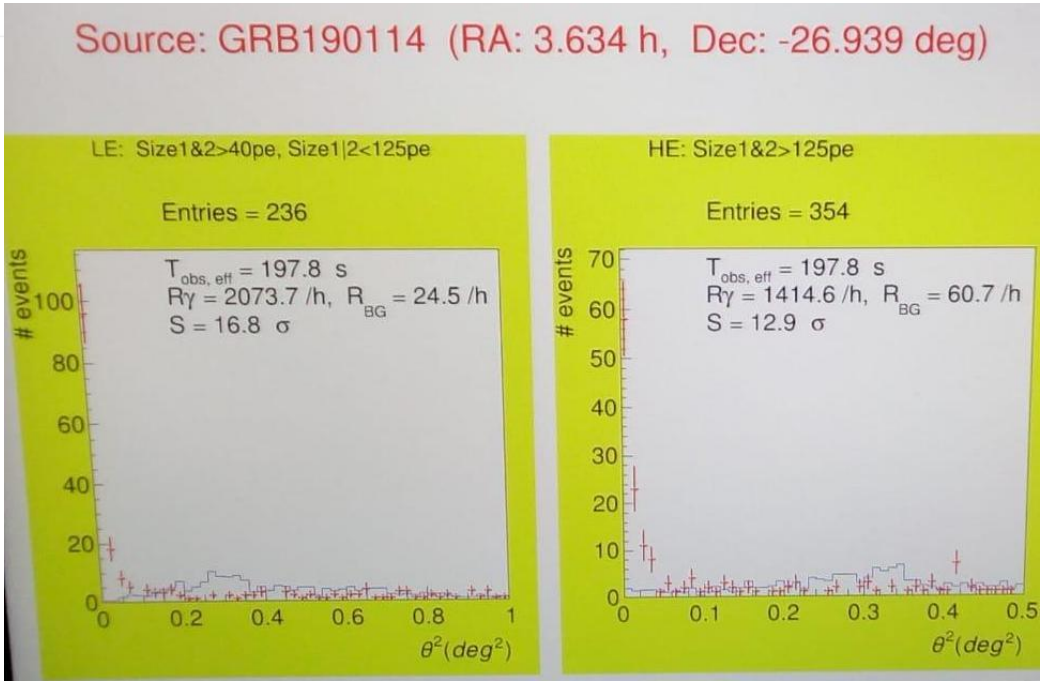
We have already issued an ATel #12390 on this very hot topic:

http://www.astronomerstelegram.org/?read=12390

and a GCN circular

https://gcn.gsfc.nasa.gov/gcn3/23701.gcn3

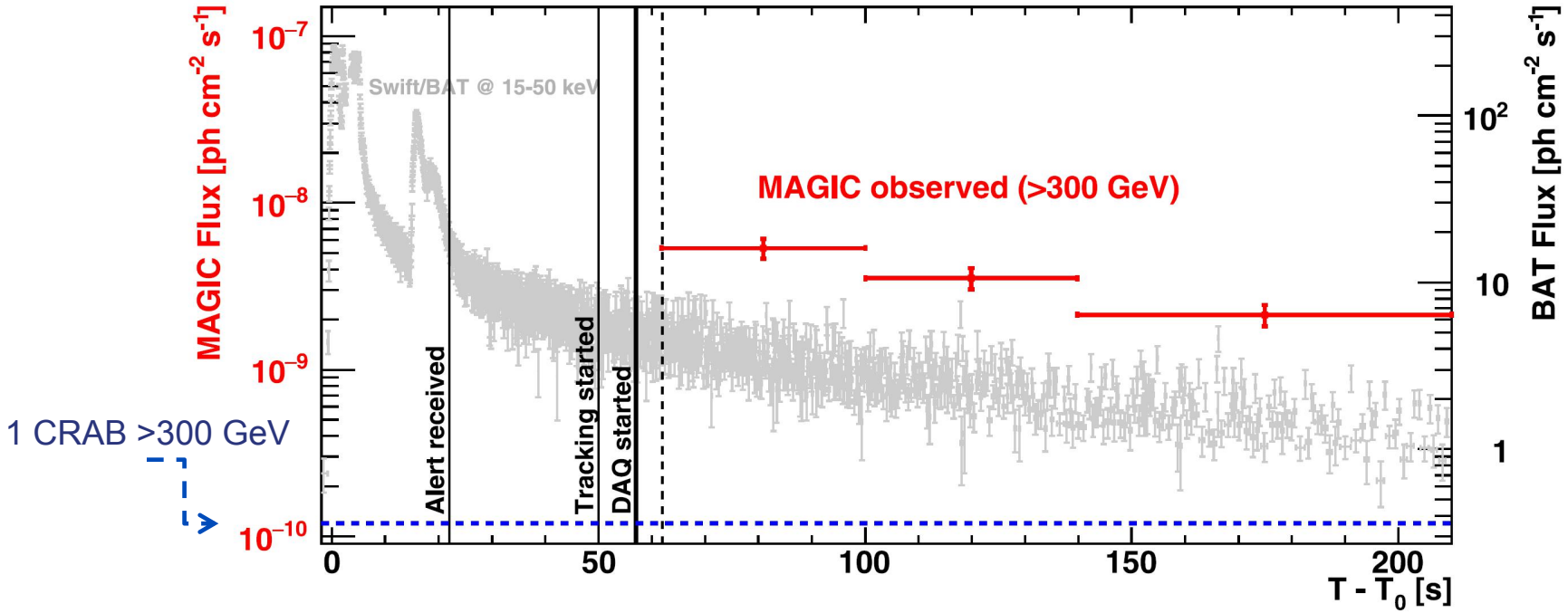
The first GRB detected at very-high-energies!



MAGIC real-time analysis after ~3min
Credit: Elena, Cosimo, Mitsunari

The Rosetta stone: GRB 190114C

- GRB 190114C: very bright long (T90~360s) GRB first detected by Swift-BAT and Fermi-GBM, later detected by multiple instruments from radio to TeV
- Quite close to Earth for a long GRB: z=0.4245
- MAGIC observed with a ~50s delay, but at relatively high zenith and with moon



GRB 190114C: some memories

- Huge work from the beginning to make sense of the data
- A dozen of analyses in the following days
- Weekly meetings open to all collaboration to discuss the progress of analyses and papers
- Crazy months, but with some nice interludes :)

Finally out!

Article | Published: 20 November 2019

Teraelectronvolt emission from the γ-ray burst GRB 190114C

MAGIC Collaboration

Nature **575**, 455–458 (2019) | Cite this article

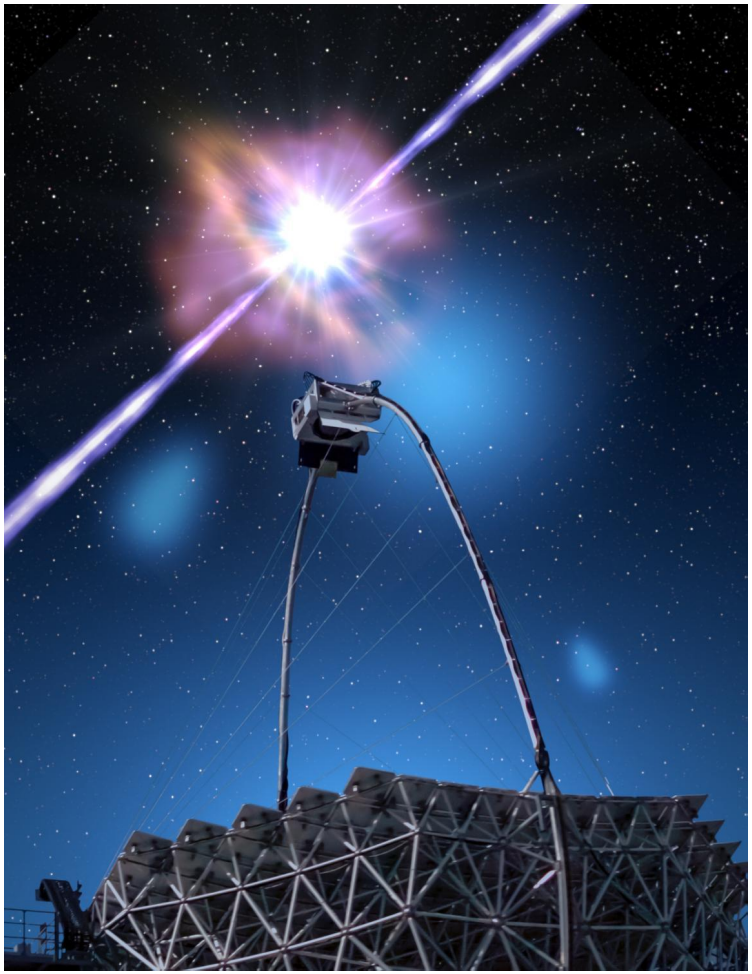
Article | Published: 20 November 2019

Observation of inverse Compton emission from a long γ-ray burst

MAGIC Collaboration, P. Veres, P. N. Bhat, M. S. Briggs, W. H. Cleveland, R. Hamburg, C. M. Hui, B. Mailyan, R. D. Preece, O. J. Roberts, A. von Kienlin, C. A. Wilson-Hodge, D. Kocevski, M. Arimoto, D. Tak, K. Asano, M. Axelsson, G. Barbiellini, E. Bissaldi, F. Fana Dirirsa, R. Gill, J. Granot, J. McEnery, N. Omodei, … D. R. Young

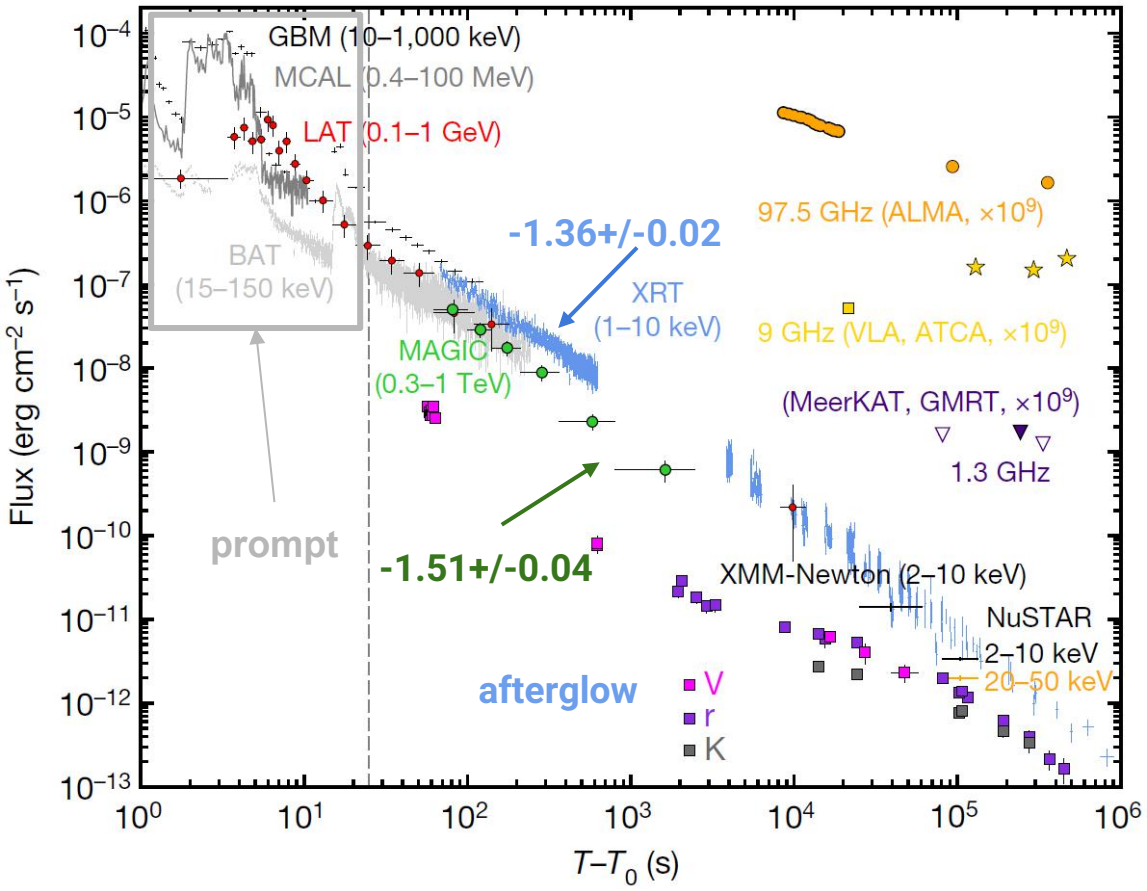
+ Show authors

Nature **575**, 459–463 (2019) | Cite this article



GRB 190114C: MWL light curve

MWL light curve for GRB 190114C: 17 orders of magnitude in energy



MAGIC Coll. et al., Nature 575, 459 (aka: MWL paper)

TeV light curve has similar smooth temporal decay as the X-ray one

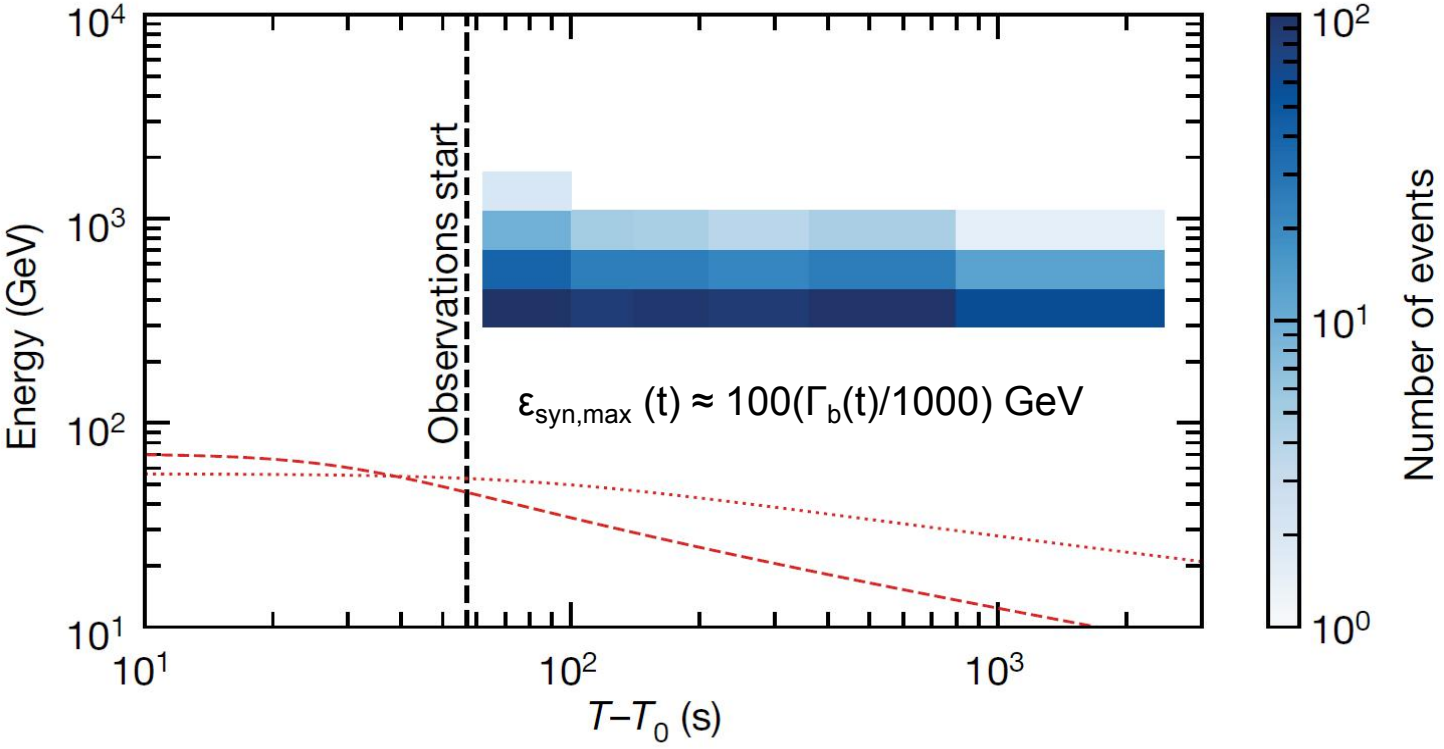
↓

TeV emission likely associated with afterglow phase of the GRB

+

link between processes generating X-rays (synchrotron) and TeV gamma rays

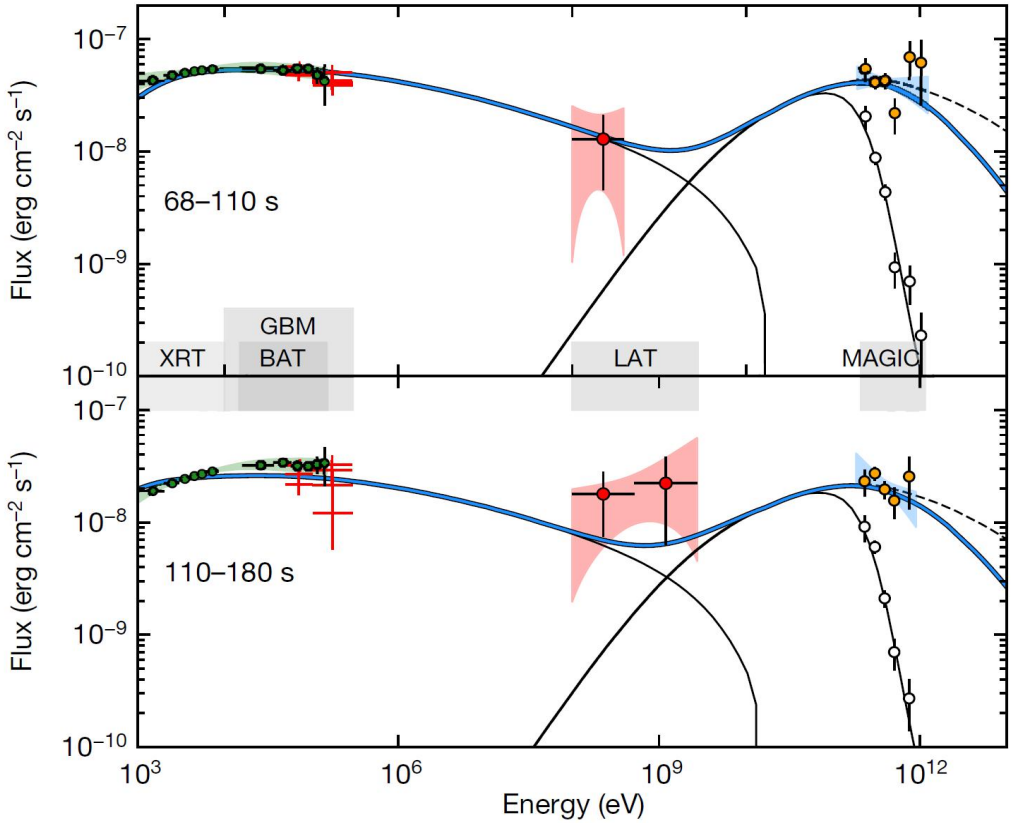
GRB 190114C: photons energy as a function of time



MAGIC Coll., Nature 575, 455 (aka: discovery paper)

Energy of photons detected by MAGIC well above the synchrotron “burnoff limit” → the emission process cannot be the same as the one producing X-rays

GRB 190114C: SSC modeling



MAGIC Coll. et al., Nature 575, 459 (aka: MWL paper)

SSC model parameters:

$E_k \sim 8 \times 10^{53}$ erg
p=2.6
n_0=0.5 (constant medium)
$\epsilon_b = 8 \times 10^{-5}$
ϵ_e=0.07

Efficient amplification of B (few microGauss in unshocked medium) to values of 0.5-5 G

Parameters of the modeling have values similar to those inferred from radio-to-GeV afterglow modeling for previous GRBs

Processes to take into account:
- Klein-Nishina
- gamma-gamma absorption

MWL broadband emission can be modeled by synchrotron self-Compton (SSC) in the forward shock → new emission component!

GRB 190114C: LIV studies

- One can use the observed light curve and spectrum to build the likelihood of detecting a LIV effect at a given order n (n=1, 2) and use the maximum likelihood method to constrain the LIV parameters

- First study of this kind using GRB data at VHE, but not so sensitive (at least for n=1):
  - GRB 190114C is at moderate distance
  - it was detected during the afterglow, where light curve is decaying monotonically, so no time variability
  - comparable to past results for n=2 (here Mrk 501 is better given that Emax ~ 10 TeV)

Source	Source type	Redshift	$E_{QG,1}$ [10^{19} GeV]	$E_{QG,2}$ [10^{10} GeV]	Instrument	
GRB 090510	GRB	0.9	9.3	13	*Fermi*-LAT[1]	
GRB 190114C	GRB	0.42	**0.58**	**6.3**	MAGIC	← **this work**
PKS 2155-304	AGN	0.116	0.21	6.4	H.E.S.S.[2]	
Mrk 501	AGN	0.034	0.036	8.5	H.E.S.S.[3]	
Mrk 501	AGN	0.034	0.021	2.6	MAGIC[4]	
Mrk 421	AGN	0.031	pending	pending	MAGIC	
Crab Pulsar	Pulsar	2.0 kpc	0.055	5.9	MAGIC[5]	

[1] Vasileiou+ (2013)
[2] Abramowski+ (2011)
[3] Abdalla+ (2019)
[4] Albert+ (2008)
[5] Ahnen+ (2017)

Not stopping there...

- Detecting GRB 190114C was a milestone, however it is not enough
  - we need more GRBs detected at VHE to understand them better!

- Here comes GRB 201216C at z=1.1!
  - paper accepted for publication on September 22nd: the 200th MAGIC paper! :)))
  - farthest source detected by IACTs so far

GCN Circular 29075

Subject GRB 201216C: MAGIC detection in very high energy gamma rays
Date 2020-12-17T17:23:13Z (3 years ago)
From Oscar Blanch at MAGIC Collaboration <blanch@ifae.es>

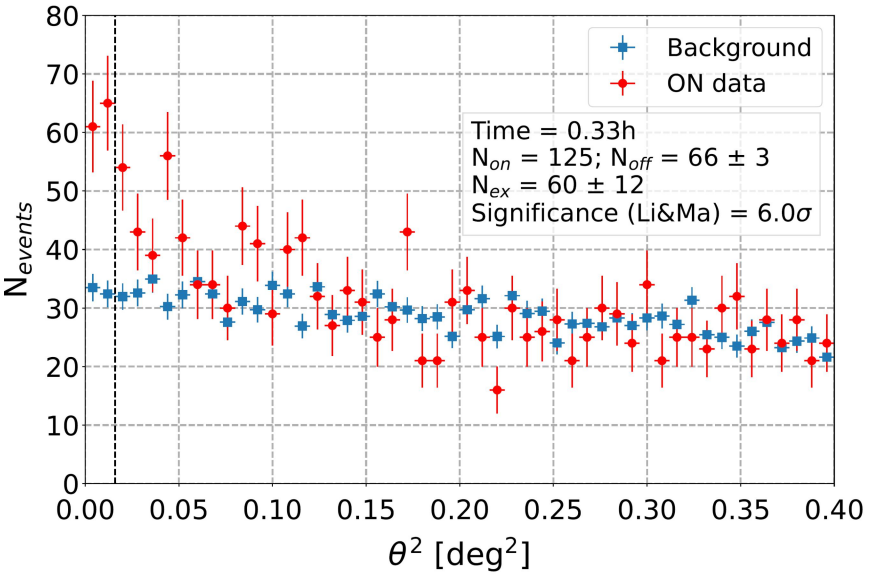
O.Blanch (IFAE-BIST Barcelona), F. Longo (University and INFN Trieste), A. Berti (INFN Torino),
S. Fukami (ICRR University of Tokyo), Y. Suda (MPP Munich), S. Loporchio (University and INFN Bari),
S. Micanovic (University of Rijeka), J. G. Green (INAF Rome), V. Pinter (IFAE-BIST),
M. Takahashi (ICRR University of Tokyo), on behalf of the MAGIC collaboration report:

On December 16, 2020, the MAGIC telescopes observed GRB 201216C following the
trigger by Swift-BAT and Fermi-GBM (Beardmore et al., GCN 29061, Fermi/GBM team GCN 29063).
MAGIC started observations under good conditions about 57 seconds after the GRB onset.
The preliminary offline analyses show an excess above 5 sigma, compatible with the GRB position reported
by the Swift and Fermi teams. Refined off-line analyses of the data are ongoing.

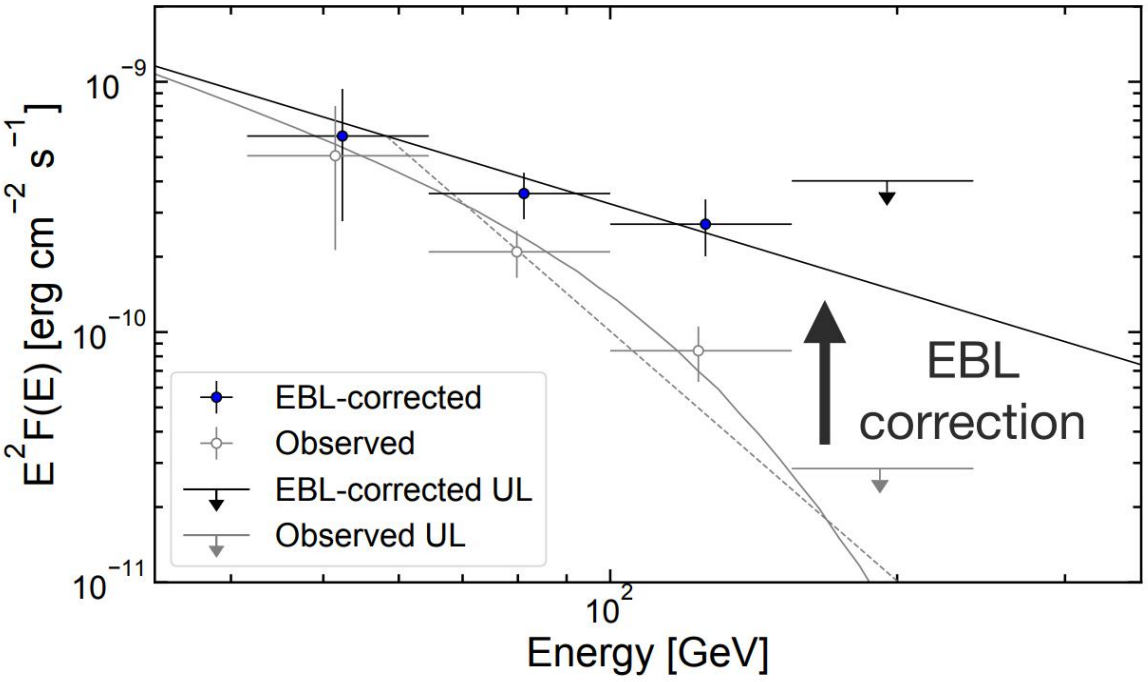
We strongly encourage follow-up observations by other instruments at all wavelengths.

The MAGIC point of contact for this burst is O. Blanch (blanch@ifae.es).
Burst Advocate for this burst is F. Longo (francesco.longo@ts.infn.it).

MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes
located at the Observatory Roque de los Muchachos on the Canary island
La Palma, Spain, and designed to perform gamma-ray astronomy in the energy
range from 50 GeV to greater than 50 TeV.

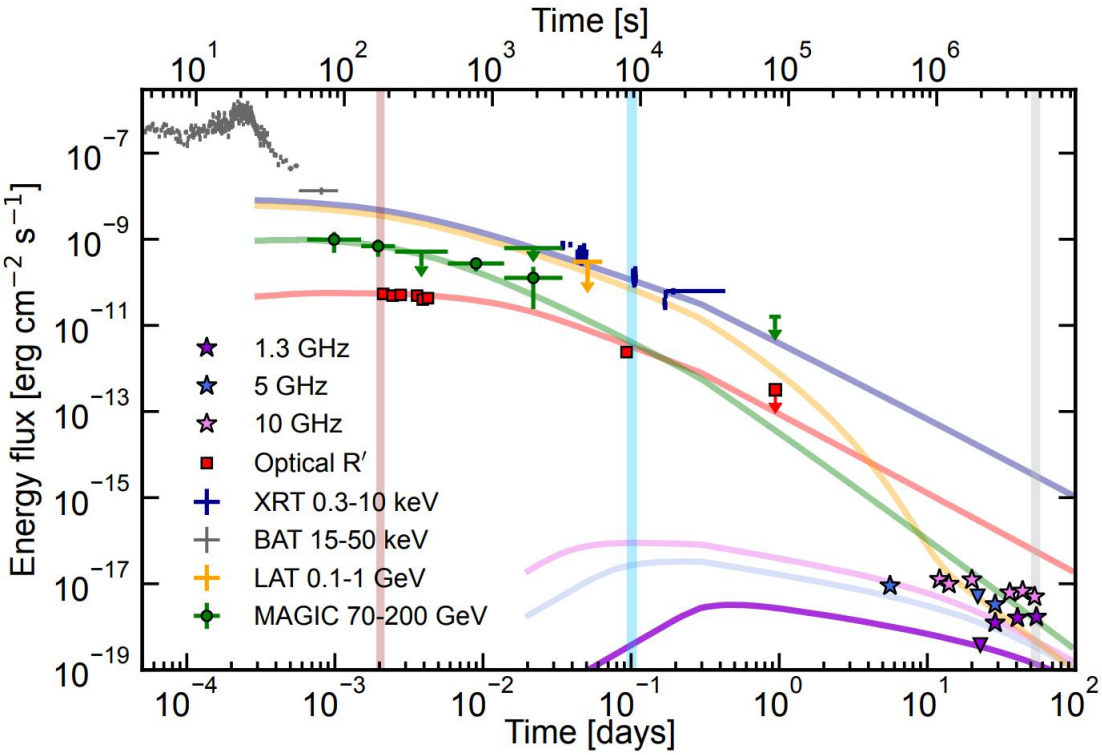


GRB 201216C: challenging analysis



- Large absorption of the VHE flux by the EBL --> steep observed spectrum with index around -5.3
- Studied systematics due to different EBL models and different energy scale

GRB 201216C: modeling



$E_k = 4 \times 10^{53}$ erg
$\theta_{jet} = 1°$
$\Gamma_0 = 180$
$n(R) = 7.5 \times 10^{33}\ R^{-2}$ cm^{-1}
$p = 2.1$
$\varepsilon_e = 0.08$
$\varepsilon_B = 2.5 \times 10^{-3}$

- MWL fluxes are consistent with the synchrotron+SSC model (Miceli&Nava 2022)
  - Sub-TeV emission is well above the maximum synchrotron energy (~10 GeV at T0+~177 s)
  - No solution found with a homogeneous density medium

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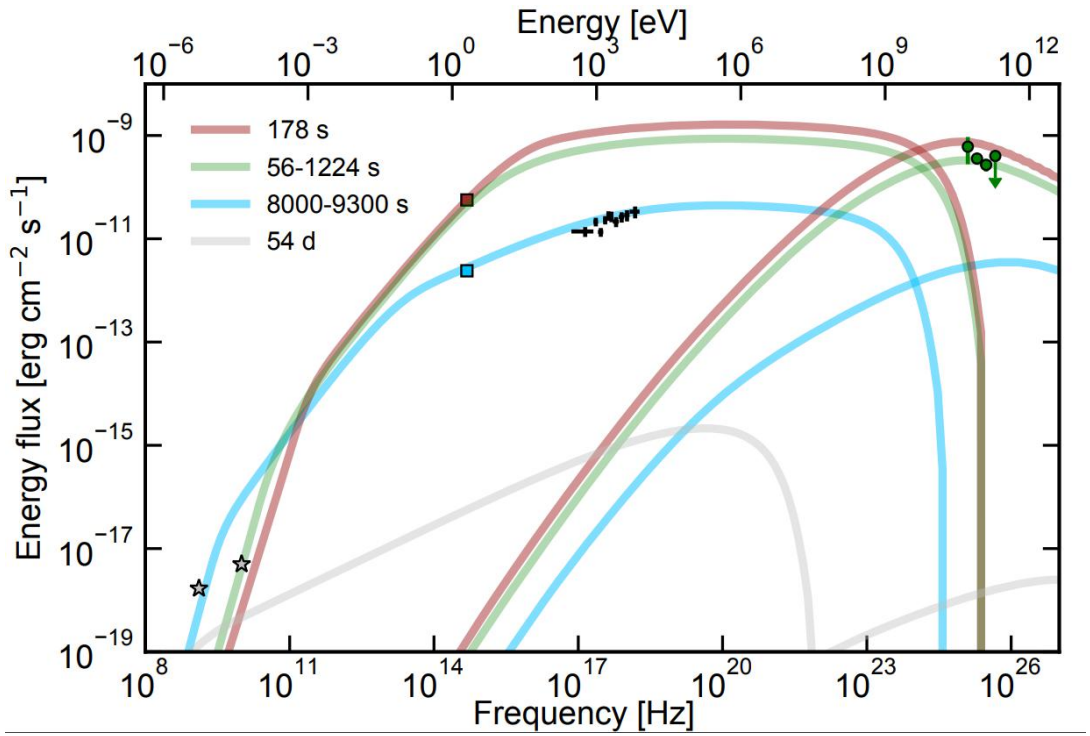

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Lessons learned

- Continued effort pays off at the end!
  - certainly technical developments played a role (alert systems, improvement in the sensitivity, lowered energy threshold, ability to observe in diverse weather conditions)
  - changes in strategies e.g. observe not only close to the onset, but also much later, especially for bright events

- VHE emission is there, it can be detected if GRB is relatively close
  - GRB 201216C is a (very welcome) exception

- VHE emission is present both in the early and late afterglow

- Similarities between flux level in X-ray and VHE bands, also similar time decay

- MWL data crucial for proper modeling of the emission
  - golden data set for GRB 190114C

- SSC as possible universal process to explain TeV emission?
  - SSC can explain GRB 180720B, GRB 190114C, GRB 201216C and possibly GRB 190829A

Prospects of GRB searches with MAGIC

- Our understanding of the afterglow emission is still uncertain despite the recent detected events
  - alternative emission models (e.g. hadronic)?
  - we need more GRBs detected at VHE!

- Another major breakthrough would be the detection of VHE emission during the prompt phase – crucial info on the emission process, still heavily debated
  - current and new ground-based wide field of view instruments (HAWC, LHAASO, SWGO...) may be better suited for this task --> see GRB 221009A example aka the BOAT

- VHE emission from short GRBs? Strong hint from GRB 160821B by MAGIC
  - interesting in relation to GW searches

- New physics?
  - Lorentz Invariance Violation (we would need a distant GRB detected in the prompt)
  - Axion-like particles (search for signatures in the spectra; GRBs detected at high redshift)
  - EBL studies?

Summary

- It took 15 years, but feasability of GRB detection with IACTs was finally proven with MAGIC!

- Even with two events detected by MAGIC, a wealth of information on emission mechanism
  - additional component
  - preference for wind-like scenarios?
  - jet opening angle
  - magnetic field
  - ....

- We keep continuing the follow-up, we want/need more GRBs at VHE!
  - however, also non detected GRBs can be used for constraining models

- A GRB+GW+neutrino event in the future?