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MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

# The MAGIC view of gamma-ray bursts at very high energies


Alessio Berti
(Max Planck Institute for Physics)
M. Artero, K. Asano, Z. Bosnjak, A. J. Castro-Tirado, S. Covino, S. Fukami, S. Inoue, F. Longo, S. Loporchio, D. Miceli, R. Mirzoyan, E. Moretti, L. Nava, K. Noda, M. Palatiello, D. Paneque, A. Stamerra, Y. Suda, K. Terauchi, I. Vovk

on behalf of the MAGIC collaboration


TeVPA 2022, 11th August 2022

# The MAGIC collaboration


We operate our telescopes in a nice place, which is usually a quiet one...

# The MAGIC collaboration


...unless a volcano erupts close to the observatory!

# MAGIC as GRBs hunter

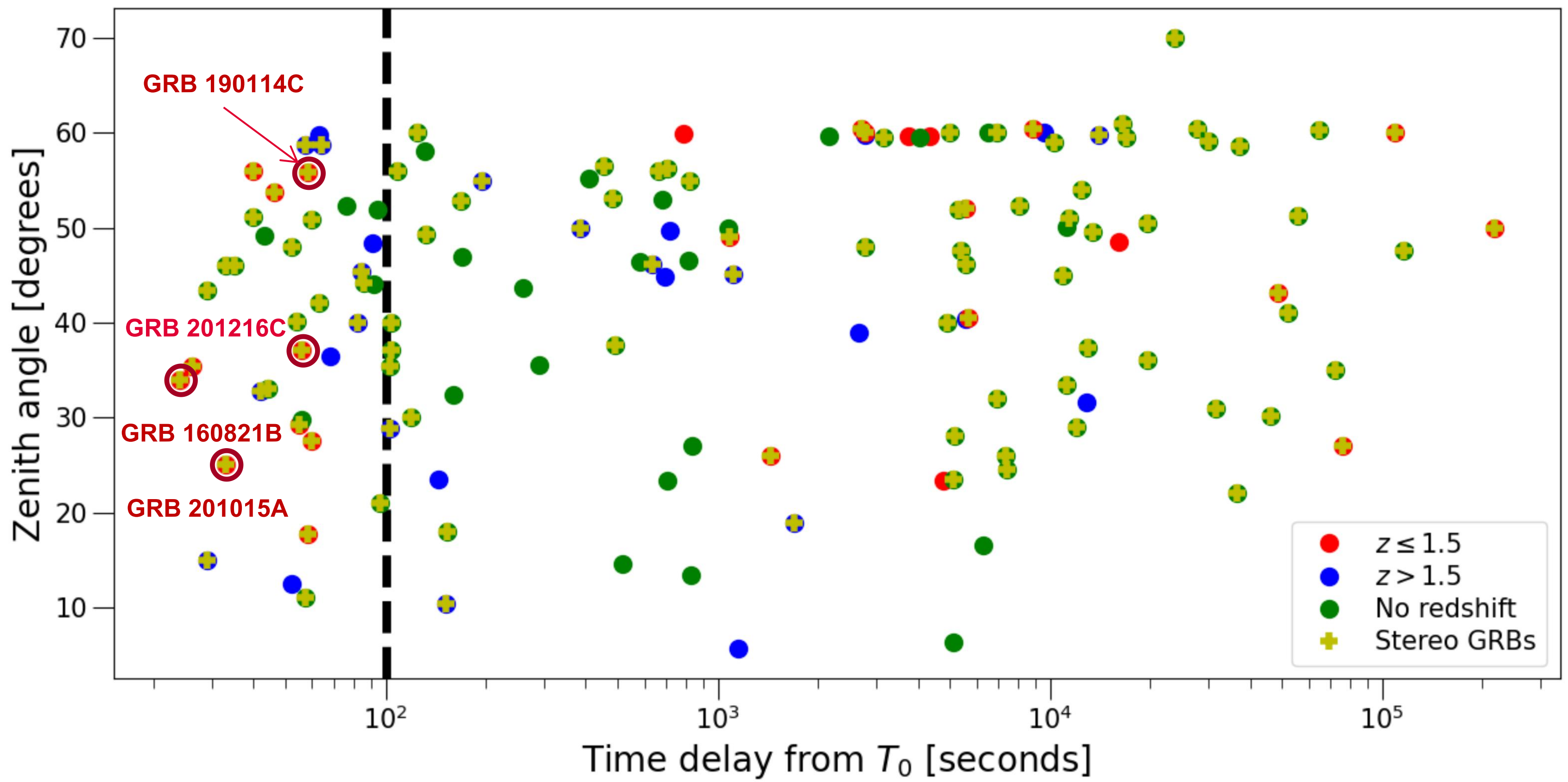
The MAGIC telescopes are particularly suited for GRB follow-ups:

- low energy threshold (~50 GeV, even lower with SumT)
- good sensitivity and large effective area
- observations during moon time and high zenith angles
- light-weight (~70 ton each telescope)
- automatic reaction to alerts and fast slewing (~7deg/s in fast mode)

GRB detection at VHE as primary scientific goal

- ~140 GRBs observed since 2005
- 2 detections: GRB 190114C and GRB 201216C
- 2 hints of detection: GRB 160821B and GRB 201015A
- late time observations for specific GRBs (e.g. with LAT detection)
    - change of strategy after GRB detections, not limited to 4h after the trigger time → trying to catch also late afterglow emission

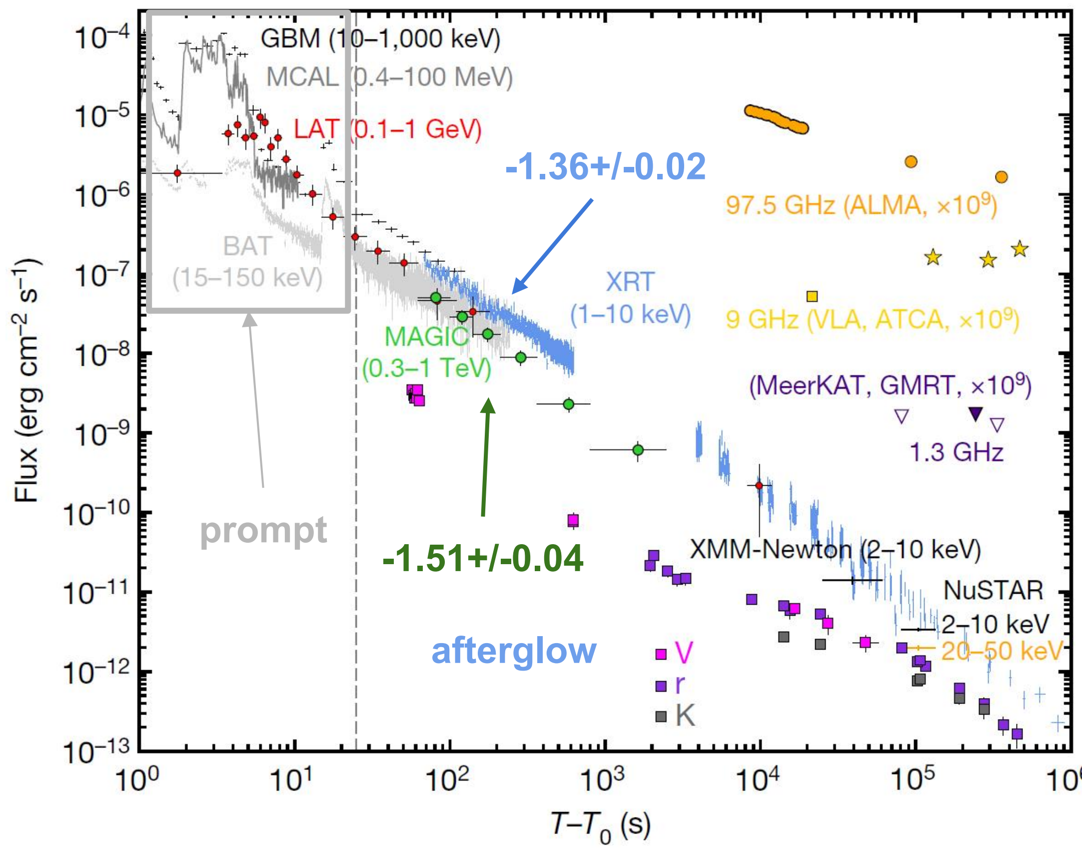
# Historical GRB follow-up by MAGIC




Huge effort in GRB follow-up, finally paying off in 2019

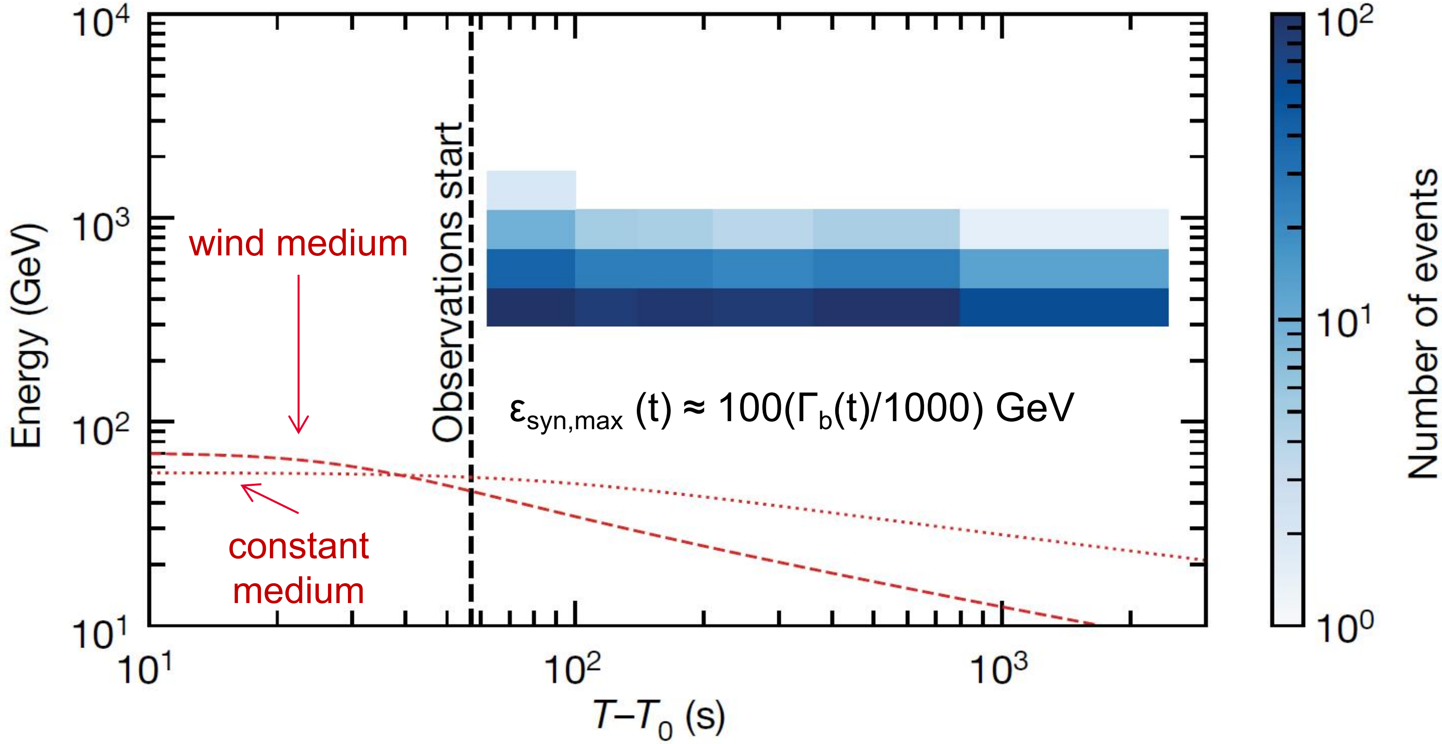
# GRB 190114C

- Bright, long GRB
  - $T_{90}$~360 s
  - $E_{iso}$~3x10$^{53}$ (1-10000 keV)
  - z=0.4245
- Follow-up by MAGIC from $T_0$+57s for 4.4h hours, detection at 50σ level in the first 20 minutes in the 300 GeV to 1 TeV range
- Flux level between 300 GeV and 1 TeV similar to that in X-ray band
- Similar, smooth flux decay in TeV and X-rays hints at a process linking the two bands




Nature 575, 455-458 (2019) & Nature 575, 459-463 (2019)

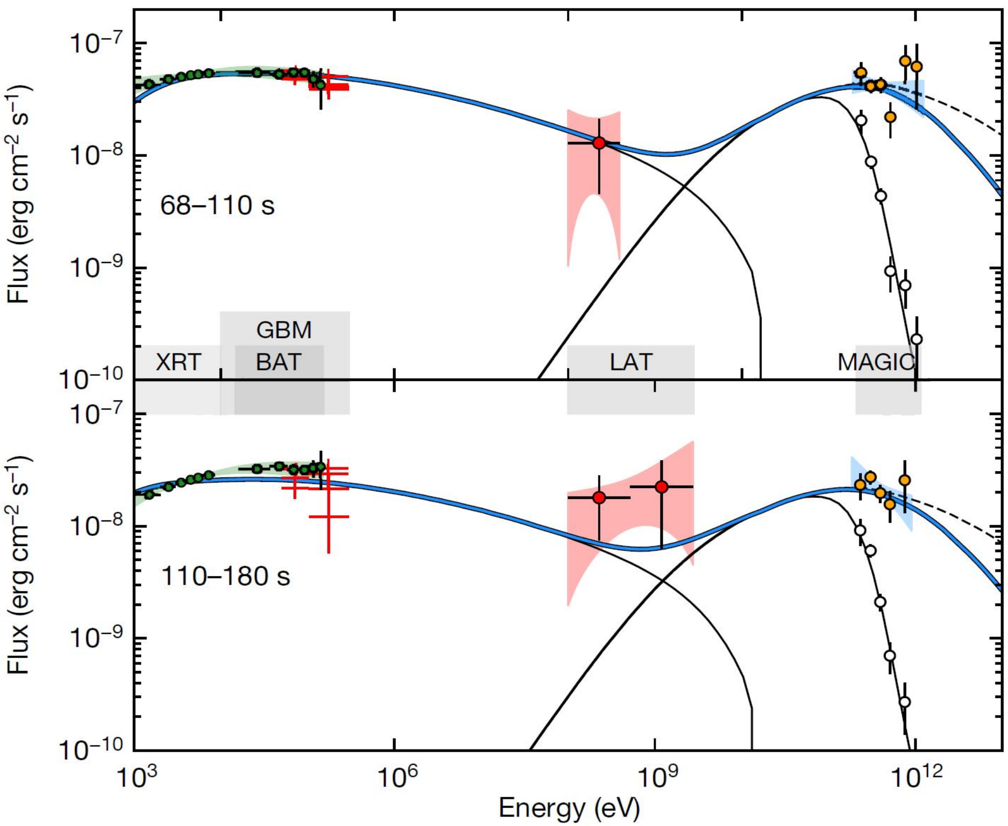
# GRB 190114C




Nature 575, 455-458 (2019) & Nature 575, 459-463 (2019)

Energy of photons detected by MAGIC above the synchrotron “burnoff limit” (case of electrons, one zone model) → the emission process cannot be the same as the one producing X-rays

# GRB 190114C




SSC model parameters (solid lines):

$E_k$~8x10$^{53}$ erg
p=2.6
$n_0$=0.5 (constant medium)
$\epsilon_B$=8x10$^{-5}$
$\epsilon_e$=0.07

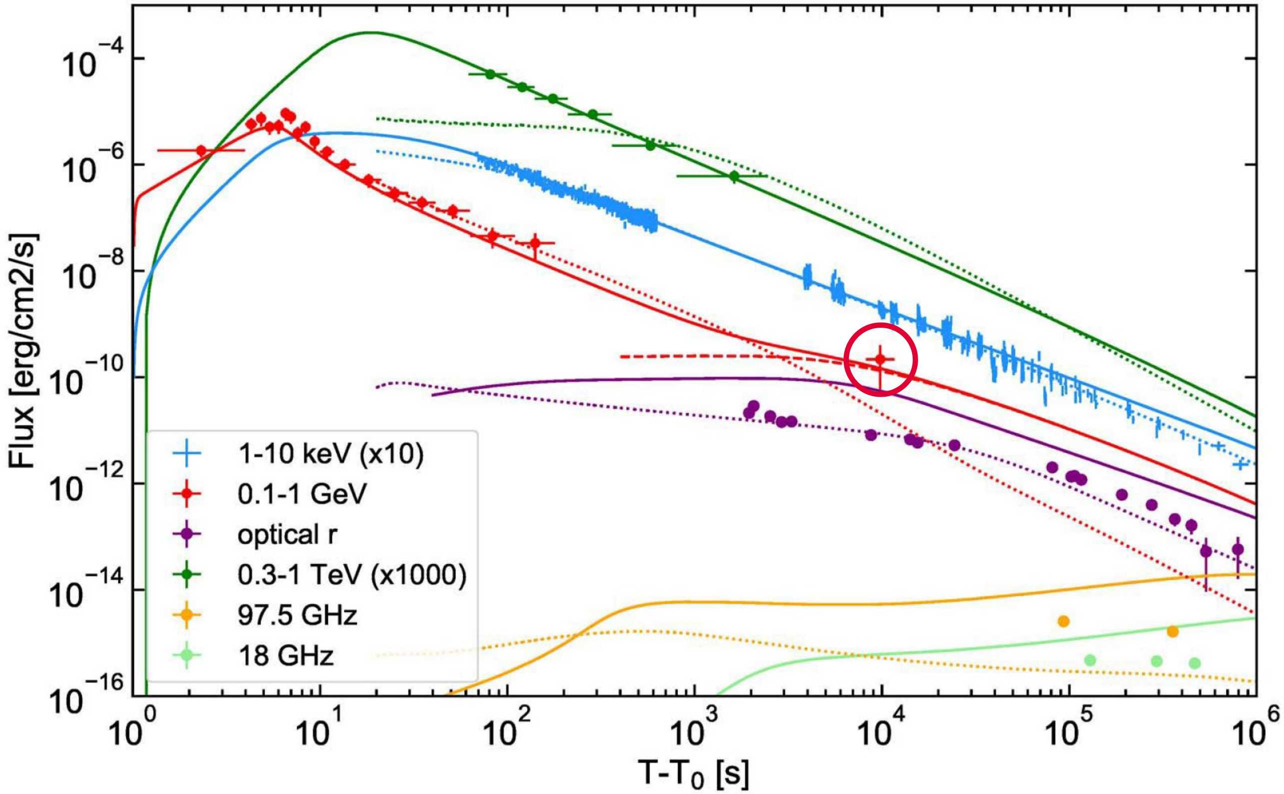
Efficient amplification of B (few uG in unshocked medium) to values of 0.5-5 G

Parameters of the model 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 → evidence of a new emission component!

# GRB 190114C

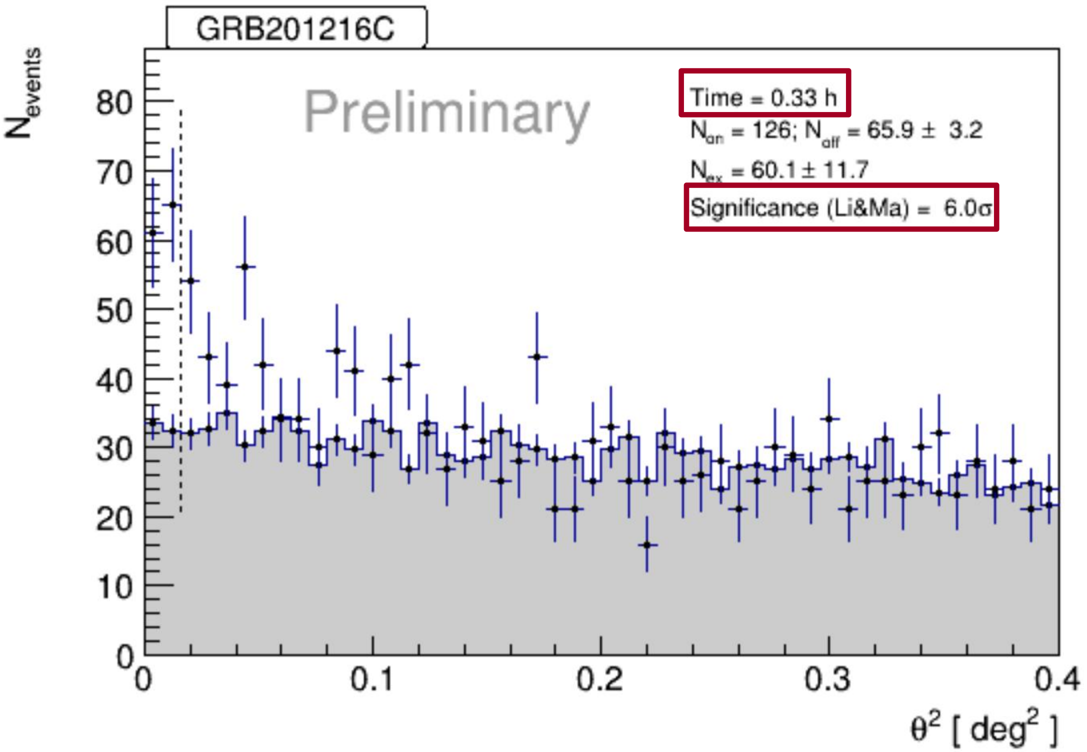



Time evolution of emission: MAGIC Coll. et al., Nature 575, 459

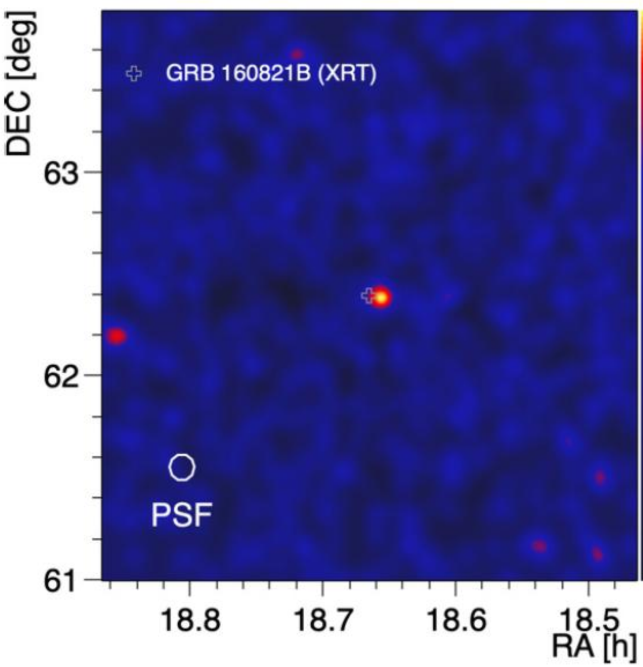
- LAT dominated by SSC at late times (dashed line), which could explain the presence of HE photons at late times above the burnoff limit seen in LAT detected GRBs
- Wind scenario agrees better for low frequency emission (dotted lines)

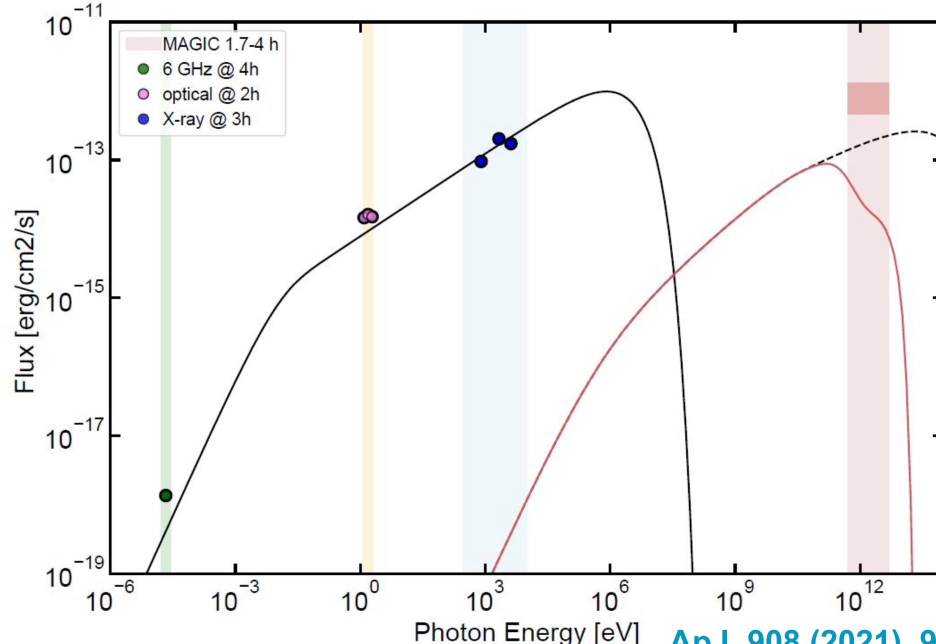
# GRB 201216C

- Long GRB (T90=48s)
- Quite bright: $E_{iso} \sim 5 \cdot 10^{53}$ erg
- Distant: z = 1.1 → the farthest VHE source detected to date!
- But... additional challenge due to high EBL absorption and non-negligible difference between EBL models for such redshift
- Detection reported by MAGIC (see GCN 29075): 6 sigma in the first 20min of observation
- Paper close to be finalized



# GRB 160821B

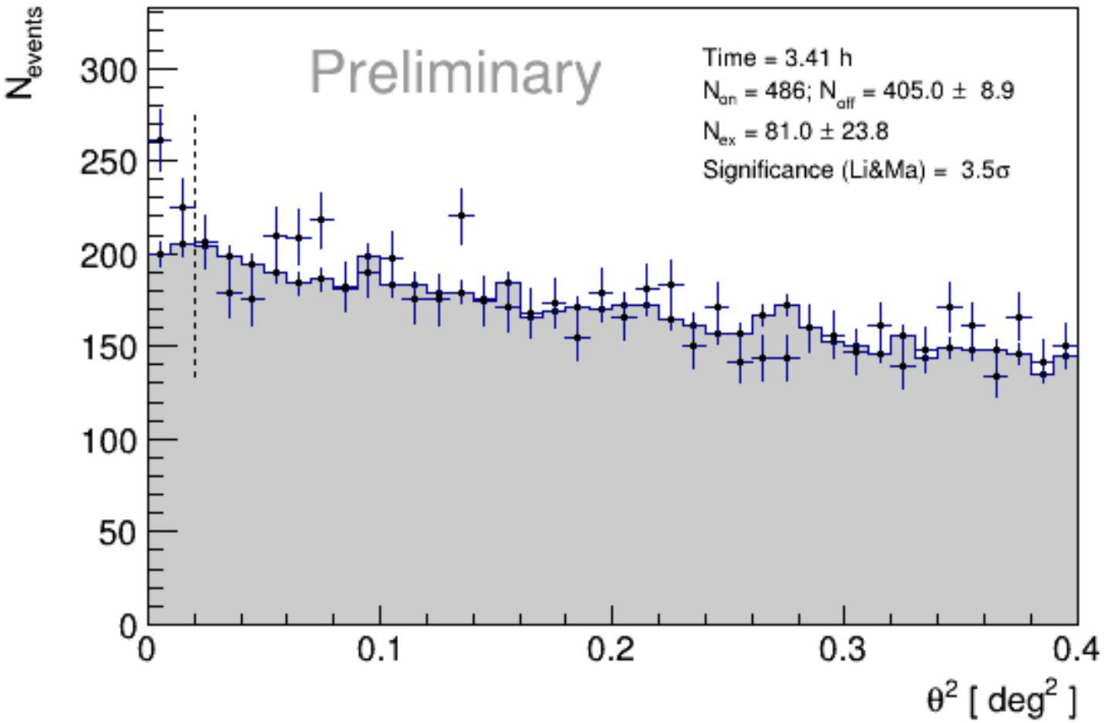


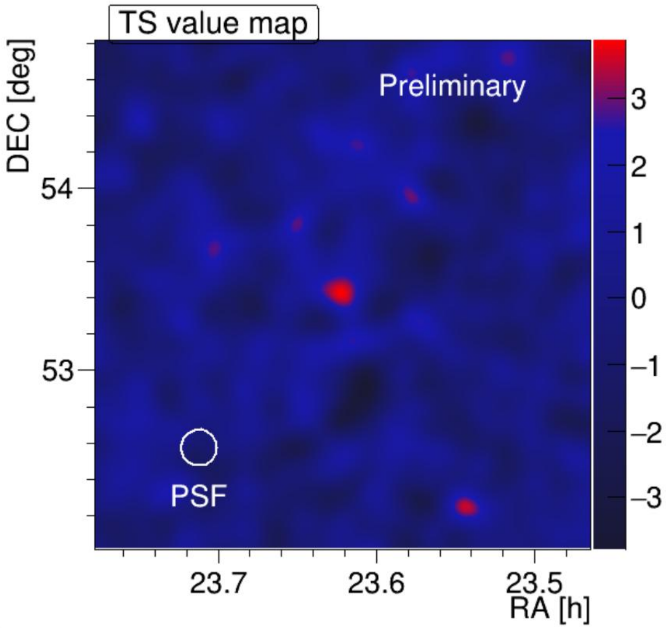




ApJ, 908 (2021), 90

- 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, the only one from IACT to date
- Kilonova emission confirmed --> progenitor most probably a BNS system
- Simplest emission model (synchrotron + SSC at external forward shock) is in tension with the TeV predicted flux
- Exciting perspectives for the next LIGO-Virgo-KAGRA run O4 (~March 2023)

# GRB 201015A




Coordinates by NOT GCN 28637:
RA = 23h 37m 16.41s
Dec = +53d 24min 56.5s

- Long GRB (T90=9.78s) → some debate about long/short nature, but SN signature was detected at T0+5 days
- Relatively low luminosity: $E_{iso}$ ~ $10^{50}$ erg --> interesting to comapre with GRB 190829A
- Quite close: z = 0.426
- Hint of detection reported by MAGIC (>3 sigma, see GCN 28659)

# GRBs at VHE: what did we learn?

1. 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
2. VHE emission may be a common feature in GRBs, and it can be detected if GRB is relatively close
3. VHE emission is present both in the early and late afterglow
4. Similarities between flux level in X-ray and VHE bands, also similar time decay
5. MWL data crucial for proper modeling of the emission
6. Indication of a SSC component peaking at VHE

# GRBs at VHE: next challenges

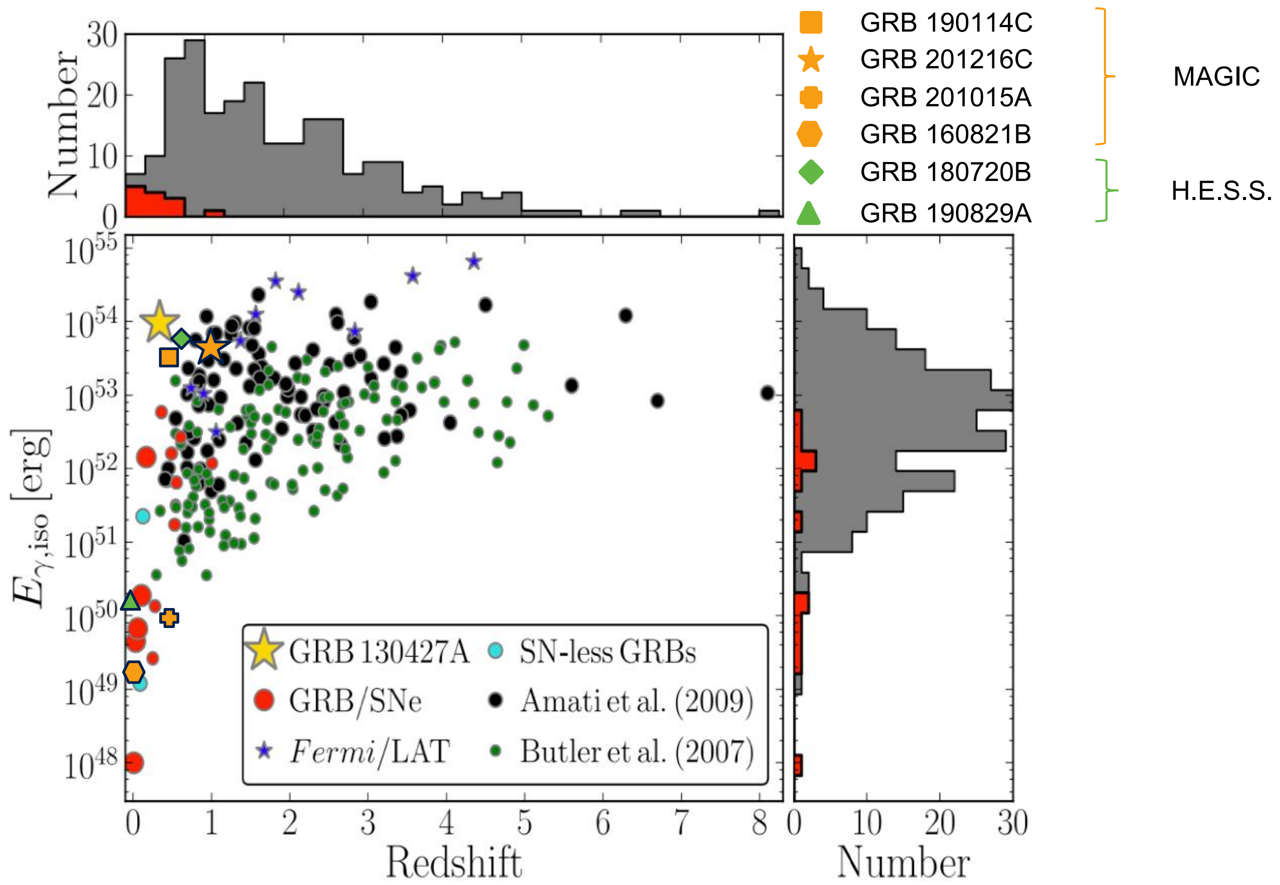
1. Our understanding of the afterglow emission is still uncertain despite the recent detected events
   - Synchrotron+SSC vs synchrotron in discussion
   - Still no clear preference for constant or wind-like external medium density
   - We need more GRBs detected at VHE!
     - Cherenkov Telescope Array (CTA) is close! Especially with upcoming Large Sized Telescopes (LSTs), if we detect a GRB from tens of GeV, we can probe the IC peak
   - Also new planned missions at keV-MeV e.g. AMEGO-X or All-Sky-ASTROGAM can better constrain the synchrotron spectrum (see Jeremy Perkins' talk from this morning)

2. 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...) might be better suited for this task

3. VHE emission from short GRBs? Strong hint from GRB 160821B by MAGIC
   - Interesting in relation to GW searches (O4 starting in March 2023)

4. 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?

# GRBs at VHE: next challenges




We detected GRBs with high and low $E_{iso}$, we can sample more of the distribution

# Summary

- MAGIC finally proved to be up for one of its main science goals, the detection of GRBs
- Two firm detections, a lot of new information available to understand GRBs better
  - indication for an SSC component in the afterglow
  - VHE emission may be common
- Other evidence of VHE emission, one from a short GRB
  - nice prospects for joint GW-GRB detections in the coming LVK run
- Trying to catch the prompt with MAGIC: not an easy task, but we may be surprised again
- Continuing our GRB follow-up program, we want and need more GRBs detected
  - current GRB statistics at VHE does not allow to reach firm conclusions
- Upcoming GRB papers
  - GRB 201216C
  - GRB 201015A
  - "catalog" with ULs from GRBs observed by MAGIC with no detection