MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

MAGIC view of gamma-ray bursts at very high energies

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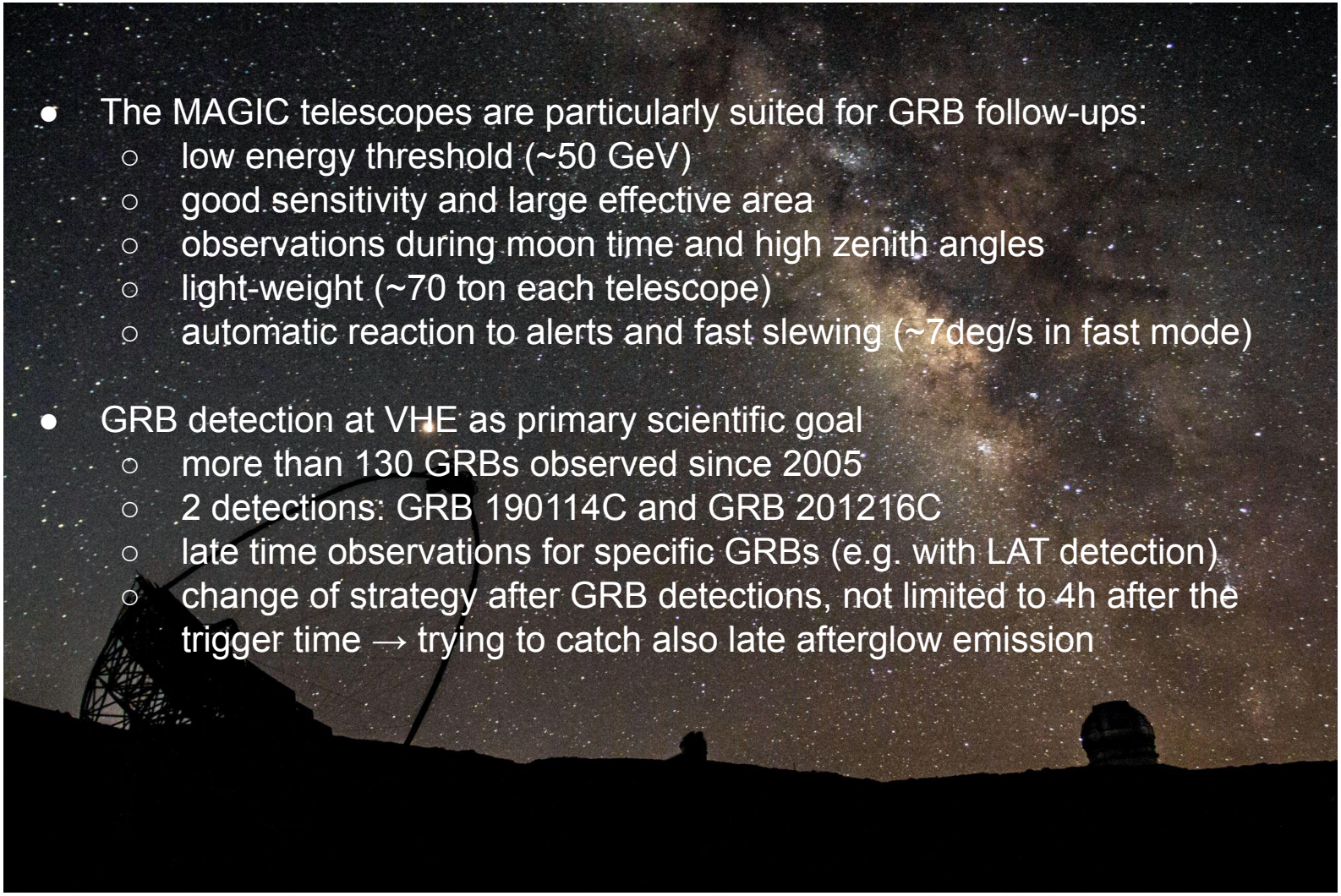
on behalf of the MAGIC collaboration

Sixteenth Marcel Grossmann Meeting

The MAGIC Collaboration

We detect gamma rays since ~18 years!

MAGIC and GRB follow-up



- The MAGIC telescopes are particularly suited for GRB follow-ups:
  - low energy threshold (~50 GeV)
  - 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
  - more than 130 GRBs observed since 2005
  - 2 detections: GRB 190114C and GRB 201216C
  - 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

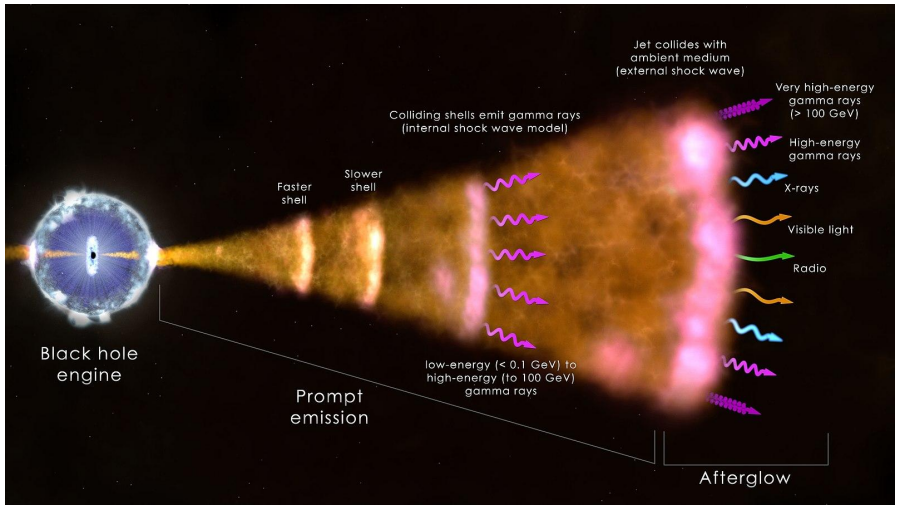
GRB VHE status at MG15 (July 2018)

Gamma-Ray Bursts: VHE status

- No detection to date
- *Fermi*-LAT HE observations show delayed and long-lasting GeV emission
- VHE observation can shed light on the delayed emission mechanism
- Hint of TeV emission from Milagrito (GRB 970417A, Atkins et al. 2000)
- All major IACTs (MAGIC, H.E.S.S. and VERITAS) have GRBs follow-up programs (before *Fermi*)
- Some interesting cases:
  - H.E.S.S. : GRB 060602B occurred within the FoV
  - VERITAS: observation of GRB 130427A
  - MAGIC: GRB 160821B (highlight of this talk)
- Pros of IACT GRB follow-up:
  - large effective area
  - high sensitivity at tens of GeV
  - relatively large FoV ($\sim$3.5°-5°)
- Cons:
  - low duty cycle
  - limited zenith range (E_{thr} depends on zenith)
  - EBL attenuation
  - Need to point, but fast repointing allows to be on target even in less than 30 s

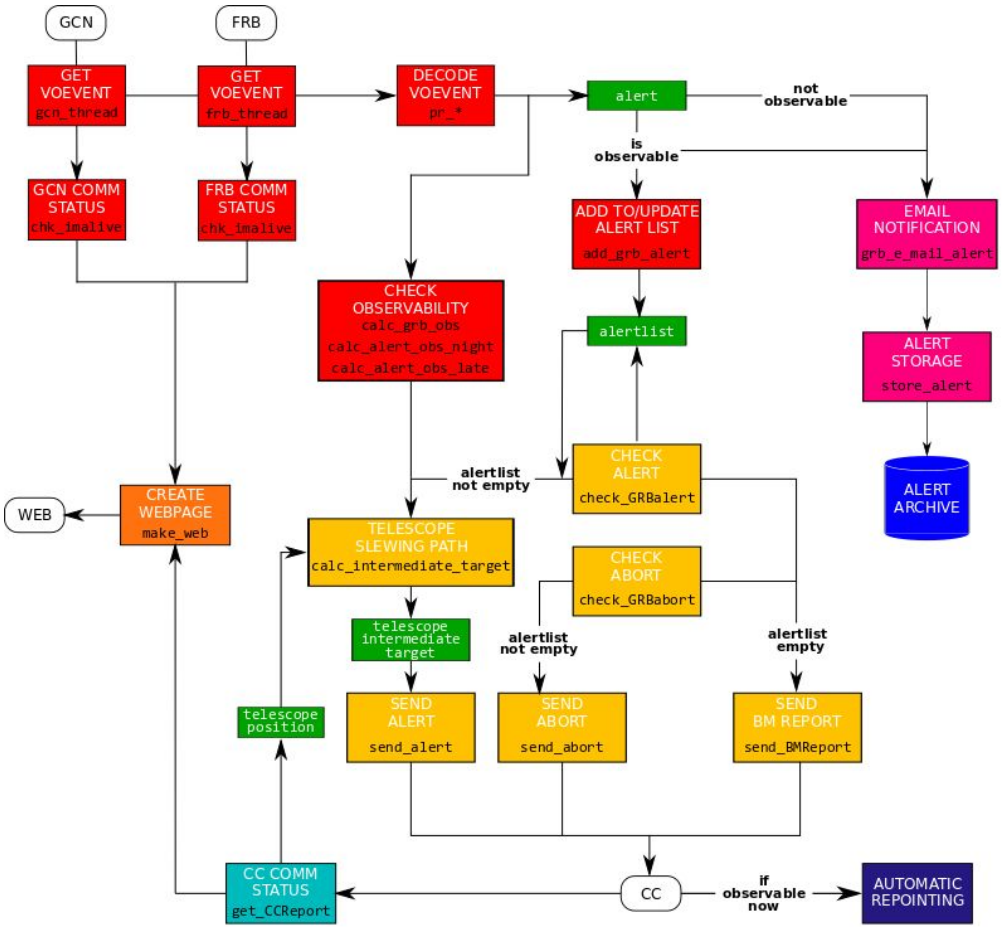
Follow-up of GRBs at very high energies

- Why is the follow-up of GRBs at very high energies (VHE, E>100 GeV) so important? Many key questions without answer:
  - do GRBs emit at VHE?
  - is VHE emission from GRBs common?
  - what is the emission process? or processes?
  - can this emission process contribute also at lower energies?
  - is there VHE emission in both the prompt and the afterglow?



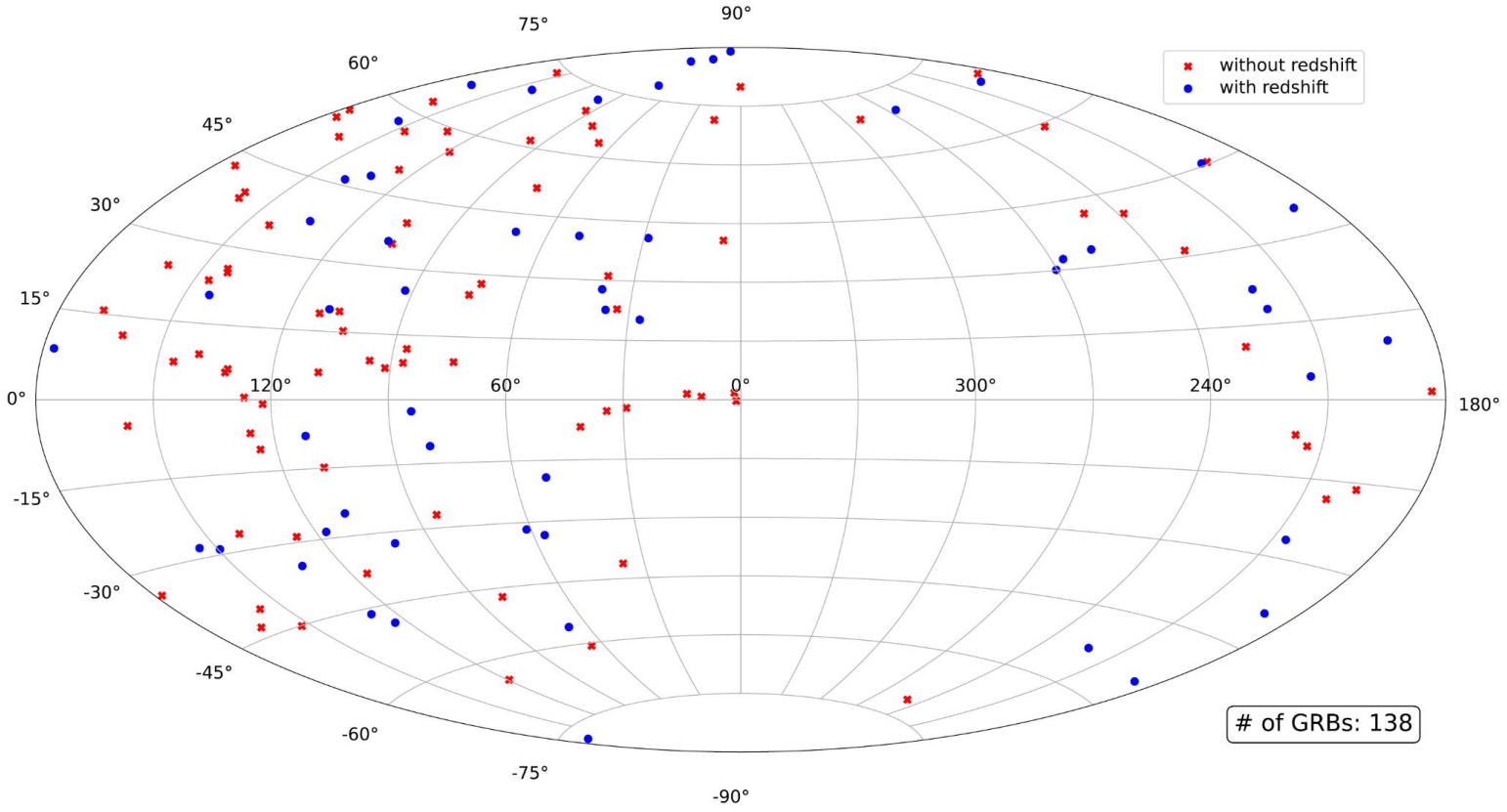
2019 was a golden year for GRB studies: two GRBs with detection published in November 2019 and one recently published in Science. Also, another detection in late 2020, plus hints from two other GRBs (one in 2016, one in 2020)

The MAGIC Automatic Alert System



- Active since 2003
- Listens to GCN Alerts, but also to other brokers (e.g. FRB)
- Automatic repointing for GRBs and neutrinos
- Recently (few months) updated to receive VOEvents
- Implements follow-up strategies
  - new GRB follow-up procedure in 2013 + late time observations
- A multimessenger system!

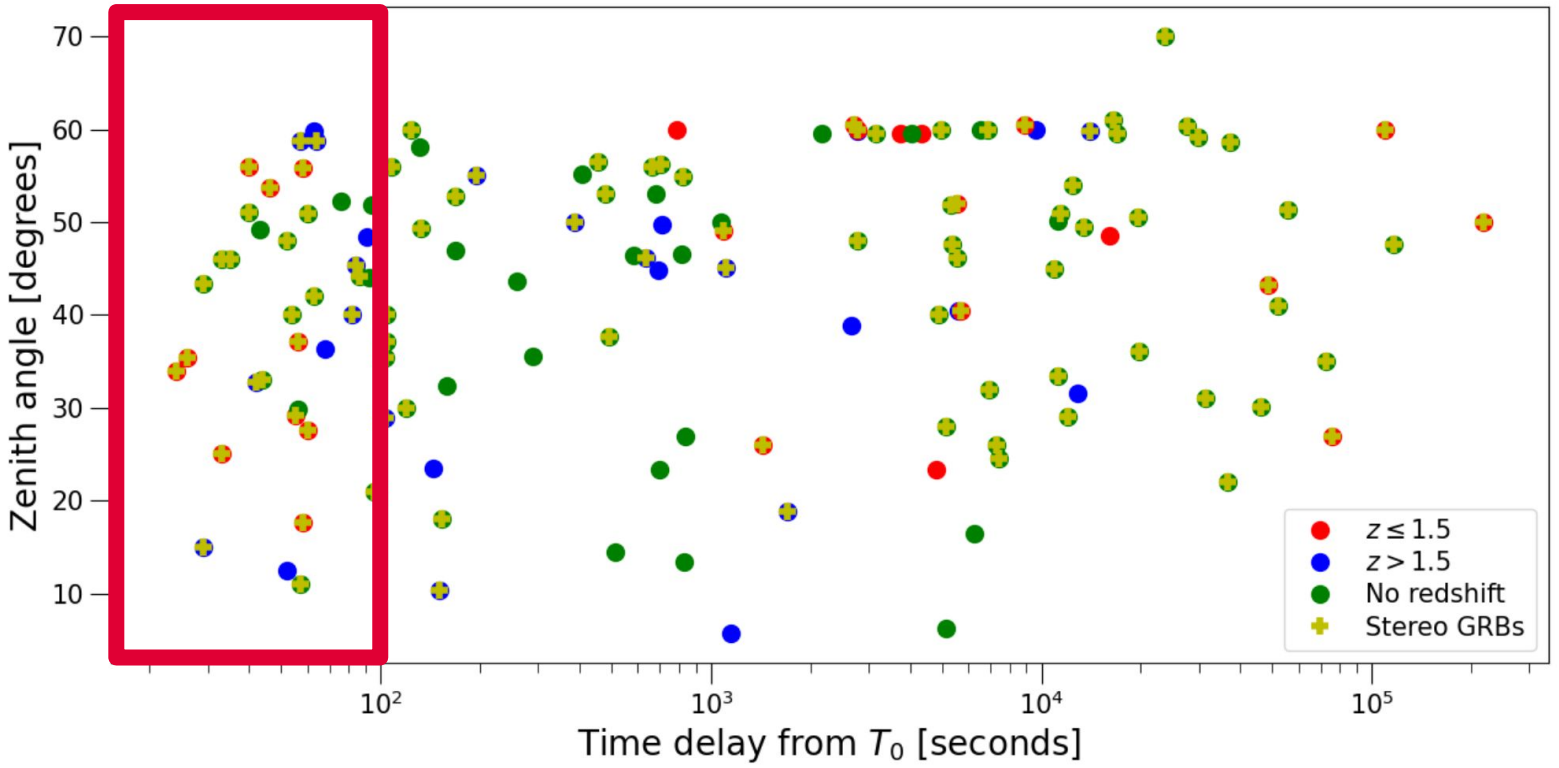
GRBs observed up to June 2021



Almost 140 GRBs (53 with redshift) observed from 2004/2005 to this date

Paper collecting results for GRBs observed from 2013 to 2019 coming soon!

GRBs observed up to June 2021



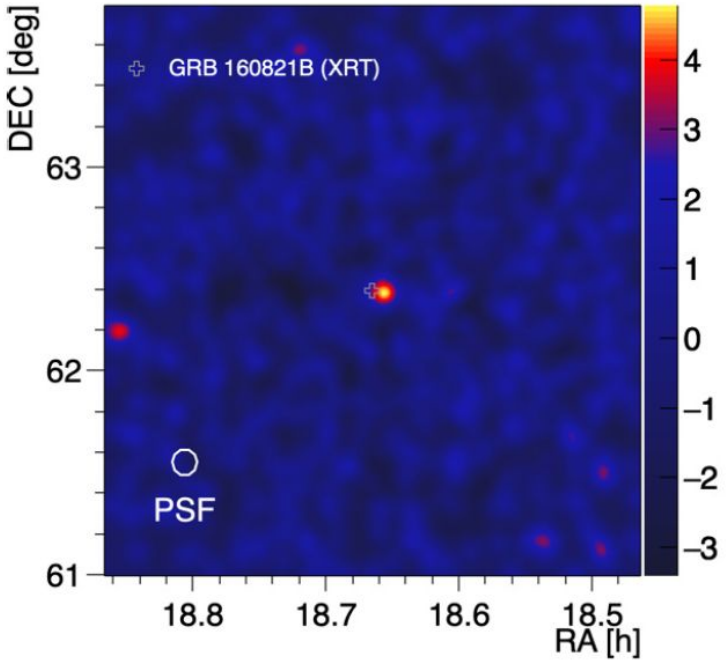
37 GRBs with delay <100s (red box), 25 with delay <60s, 12 with delay less than T_{90}
Fastest follow-up: GRB 160821B (24s after T_0)
All GRBs detected by MAGIC or with hints are in the red box (in the early afterglow phase)

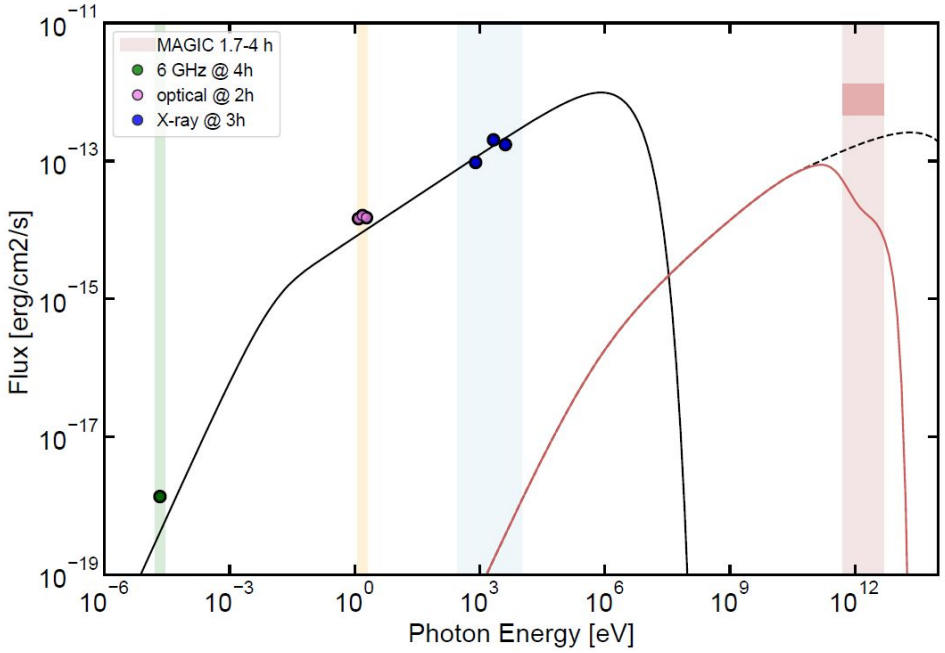
GRB VHE status at MG16 (July 2021)

From the MAGIC point of view:

- GRB 190114C: detected
- GRB 201015A: hint of detection
- GRB 201216C: detected
- refinement of the follow-up procedure
  - better organization of late-time observations to try to detect also deep in the afterglow
  - more frequent checks of MWL information (especially redshift estimations)

GRB 160821B



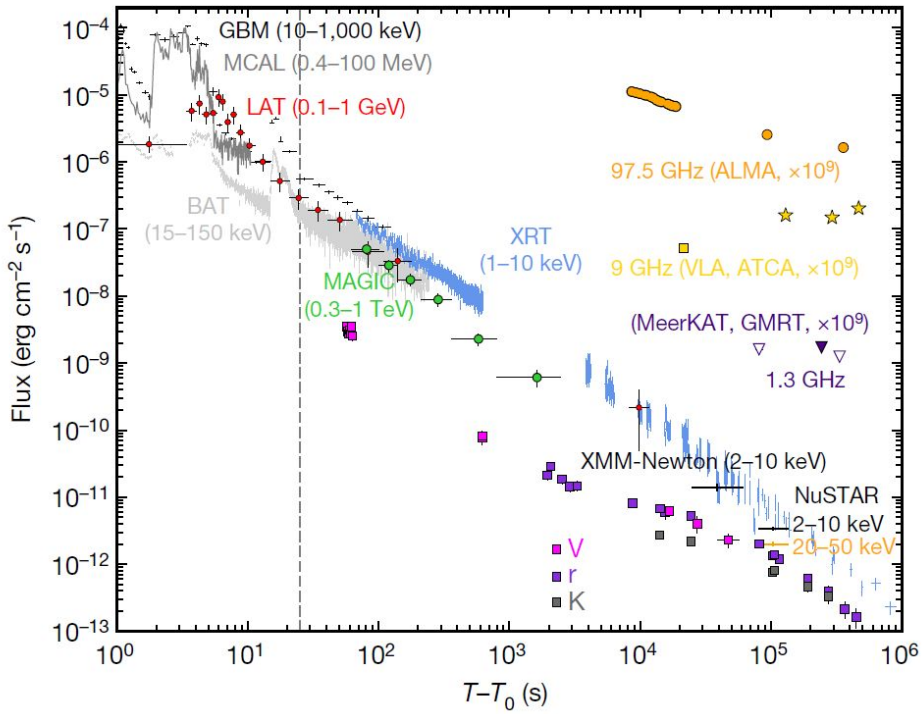


ApJ, 908 (2021), 90

- 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
- Kilonova emission confirmed
- Simplest emission model (synchrotron +SSC at external forward shock) is in tension with the TeV predicted flux

GRB 190114C

- First GRB detected by MAGIC, from 300 GeV up to 1 TeV
- VHE flux decay similar to the one in X-ray
- New emission component can be explained by synchrotron self-Compton process



Nature 575, 455 (2019)
(aka "discovery paper")

Nature 575, 459 (2019)
(aka "MWL paper")

Hear more about GRB 190114C in the next talk by Davide

GRB 201015A and GRB 201216C

- GRB 201215A
  - long GRB (T90=9.78s) → some debate about long/short nature, but SN signature was detected at T0+5days
  - relatively low luminosity: $E_{iso} \sim 10^{50}$ erg
  - quite close: z = 0.426
  - hint of detection reported by MAGIC (>3 sigma, see GCN 28659)

- GRB 201216C
  - long GRB (T90=48s)
  - quite bright: $E_{iso} \sim 5*10^{53}$ erg
  - quite distant: z = 1.1
  - detection reported by MAGIC (see GCN 29075)

More on these two GRBs during the next weeks at ICRC2021!

Summary

- Last years full of discoveries, awaited since a long time! Opened the VHE era in GRB studies

- How relevant is VHE emission? Are there any particular properties of the GRB/environment favoring VHE emission?
  - current detected GRBs do not seem to be outliers, if redshift is low enough detection may be possible
  - link with X-ray emission flux level?
  - high local column density and TeV emission relation? see Campana et al., A&A 649, A135 (2021)
  - Which other processes, different from SSC, can explain TeV emission?

- We surely need more GRBs to draw some conclusion
  - next challenges: prompt TeV emission detection, short GRB detection (together with GWs?) … MAGIC is up to it

- The way is to keep trying even more than before!