MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

MAX-PLANCK-INSTITUT
FÜR PHYSIK

ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International
Cosmic Ray Conference
12–23 July 2021

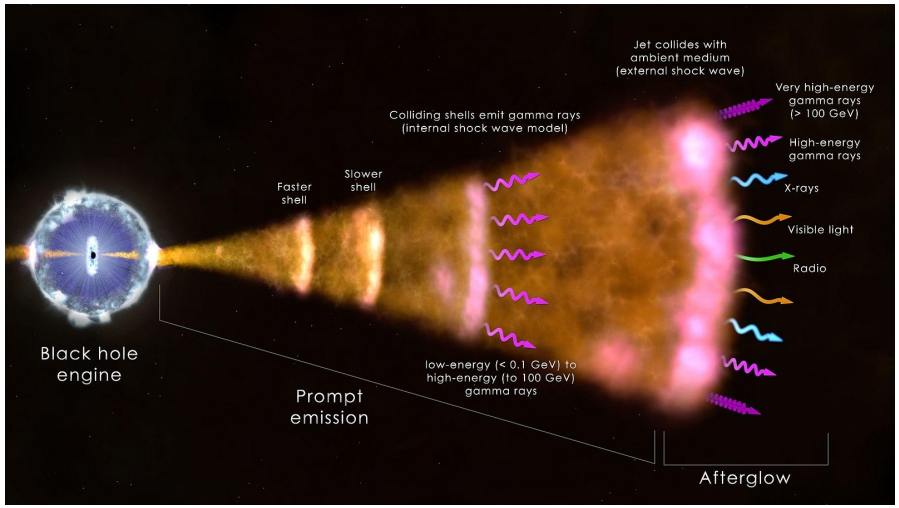
Shedding light on the highest energy emission from GRBs with MAGIC observations

Alessio Berti
(Max Planck Institute for Physics)
Z. Bosnjak, S.Covino, S. Fukami, S. Inoue, F.Longo, D. Miceli, R. Mirzoyan, E. Moretti, L. Nava, K. Noda, D. Paneque, A. Stamerra, Y. Suda
on behalf of the MAGIC collaboration

37th ICRC

The importance of the follow-up of GRBs at very high energies

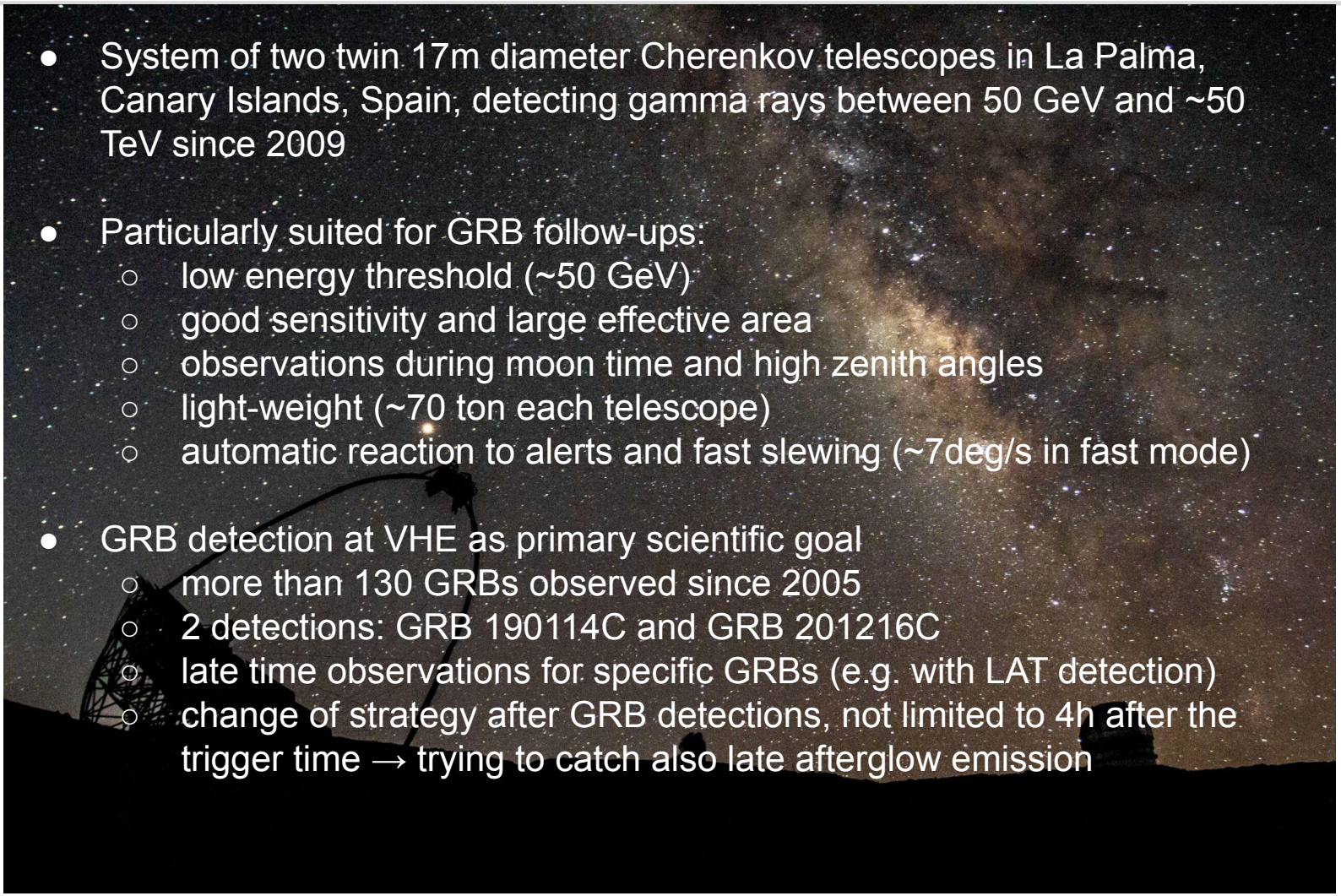
- Why is the follow-up of GRBs at very high energies (VHE, E>100 GeV) so important? Many key questions without answer:
  - do GRBs emit at VHE?
  - is VHE emission from GRBs common?
  - what is the emission process? or processes?
  - can this emission process contribute also at lower energies?
  - is 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 → I focus on the one detected by MAGIC

GRB 190114C

Introduction: the MAGIC GRB follow-up



- System of two twin 17m diameter Cherenkov telescopes in La Palma, Canary Islands, Spain, detecting gamma rays between 50 GeV and ~50 TeV since 2009

- 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

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>~2): z=0.4245 (but EBL absorption is anyway strong also at this redshift above sub-TeV energies)
- MAGIC observed with a ~50s delay, observed with moderate moon: online real-time analysis showed a significant excess at ~20 sigma in the first 20 minutes → GCN Circular and ATel issued to notify the community and encourage MWL follow-up observations

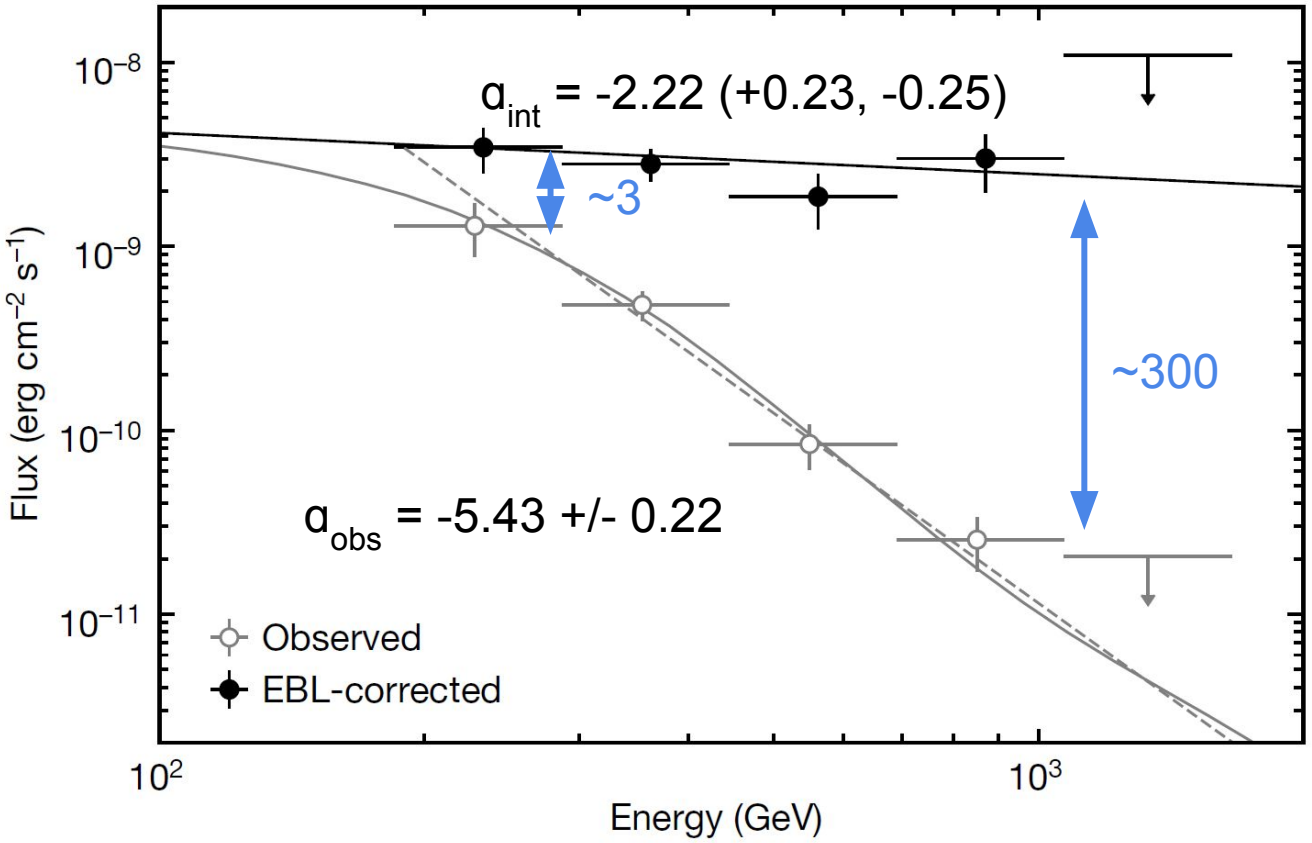
TITLE: GCN CIRCULAR
NUMBER: 23701
SUBJECT: MAGIC detects the GRB 190114C in the TeV energy domain
DATE: 19/01/15 01:56:36 GMT
FROM: Razmik Mirzoyan at MPI/MAGIC <Razmik.Mirzoyan@mpp.mpg.de>

R. Mirzoyan (MPP Munich), K. Noda (ICRR University of Tokyo), E. Moretti (IFAE Barcelona), A. Berti (University and INFN Torino), C. Nigro (DESY Zeuthen), J. Hoang (UCM Madrid), S. Micanovic (University of Rijeka), M. Takahashi (ICRR University of Tokyo), Y. Chai (MPP Munich), A. Moralejo (IFAE Barcelona) and the MAGIC Collaboration report:

On January 14, 2019, the MAGIC telescopes located at the Observatorio Roque de los Muchachos on the Canary island of La Palma, detected very-high-energy gamma-ray emission from GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, J. Selsing et al. GCN 23695). The observation was triggered by the Swift-BAT alert and it started about 50s after the Swift T0: 20:57:03.19. The GRB data of MAGIC shows a clear excess of gamma-ray events with the significance >20 sigma in the first 20 min (starting at T0+50s) for energies >300GeV. The relatively high detection threshold is due to the large zenith angle of observations (~60 deg.) and the presence of partial moon. After the first bright flash the source is quickly fading.

The MAGIC point of contact for this burst is R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de).
Burst Advocate for this burst is K. Noda (<mailto:nodak@icrr.u-tokyo.ac.jp> nodak@icrr.u-tokyo.ac.jp)

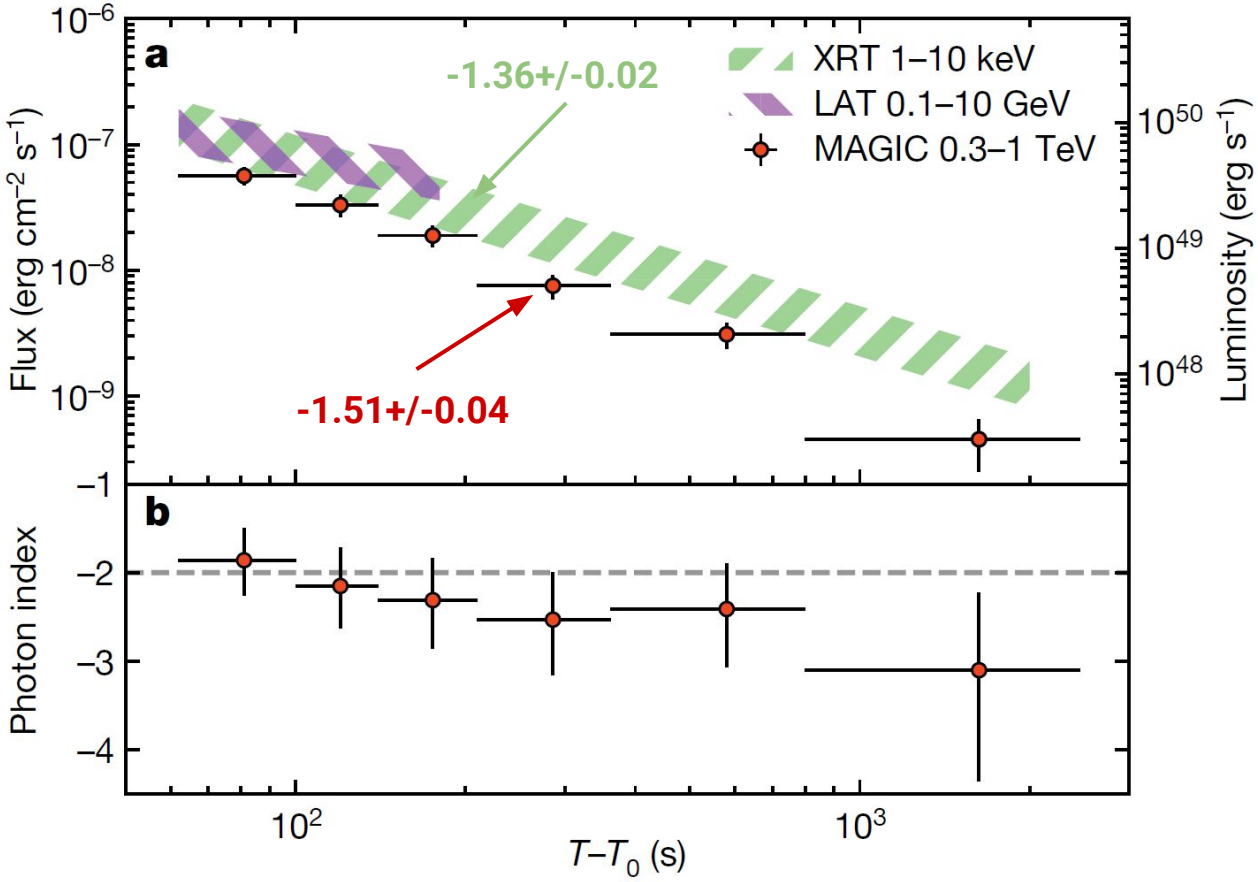
GRB 190114C: time integrated spectra



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

Time integrated spectrum (T_0+62s to T_0+2454s) → huge absorption by EBL, emission extending up to 1 TeV, intrinsic spectrum compatible with α=-2

GRB 190114C: TeV, GeV and X-ray light curve

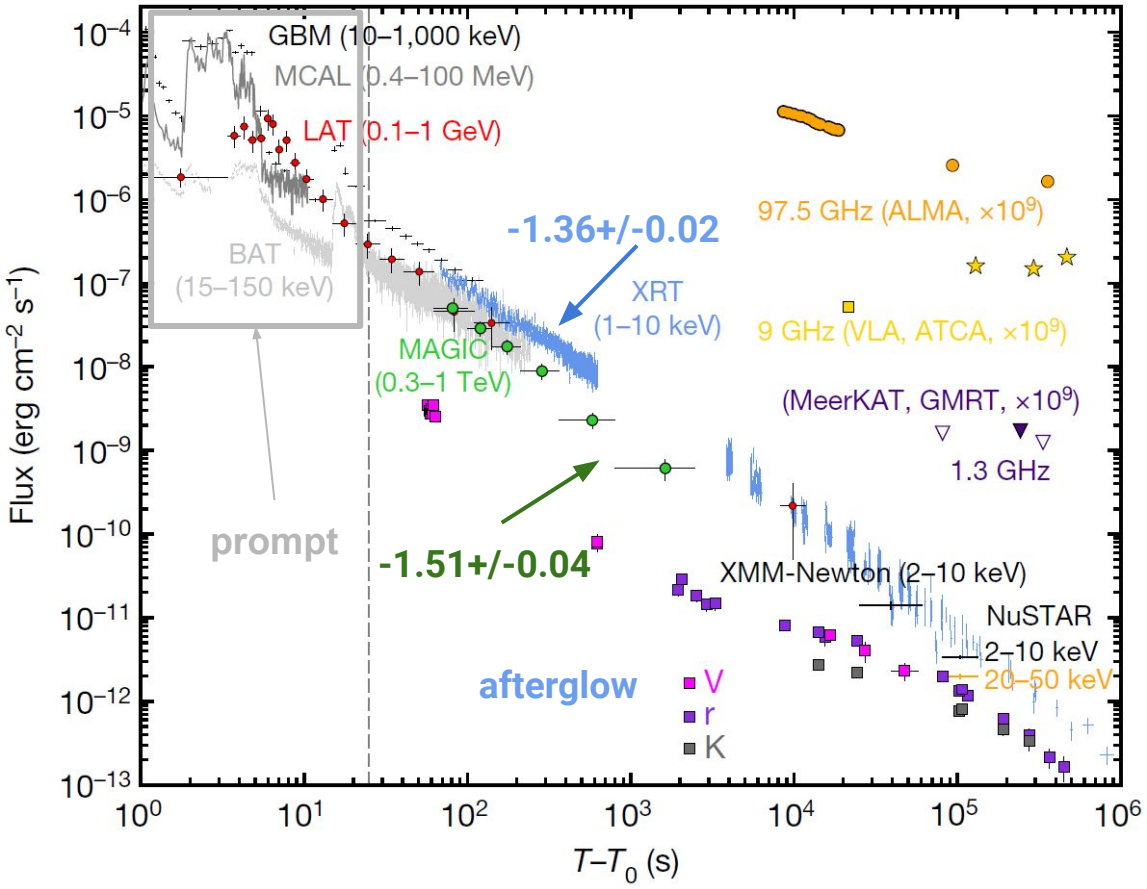


MAGIC Coll., Nature 575, 455 (aka: discovery paper)

Similar time dependence of X-ray and TeV light curves → link between processes generating X-rays (synchrotron) and TeV gamma rays

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

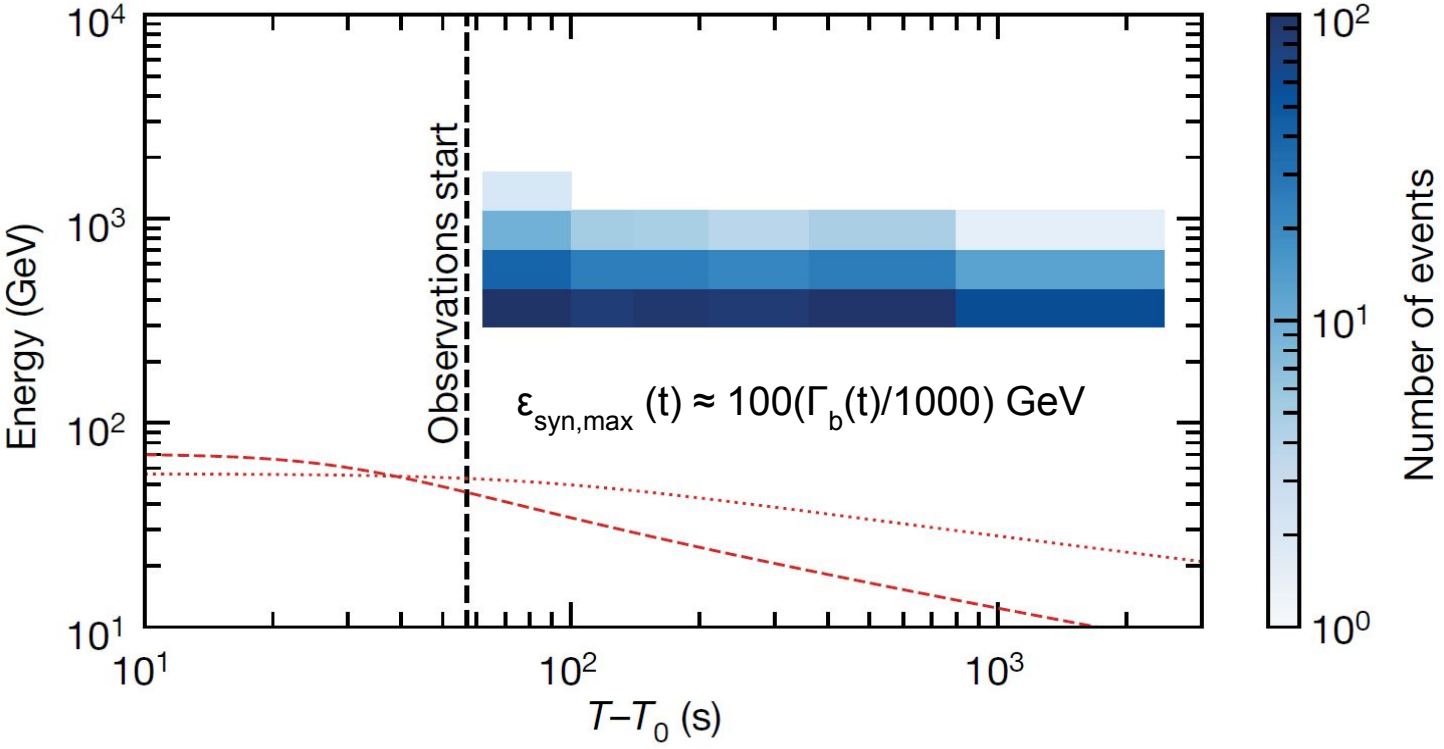
↓

TeV emission likely associated with afterglow phase of the GRB

+

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

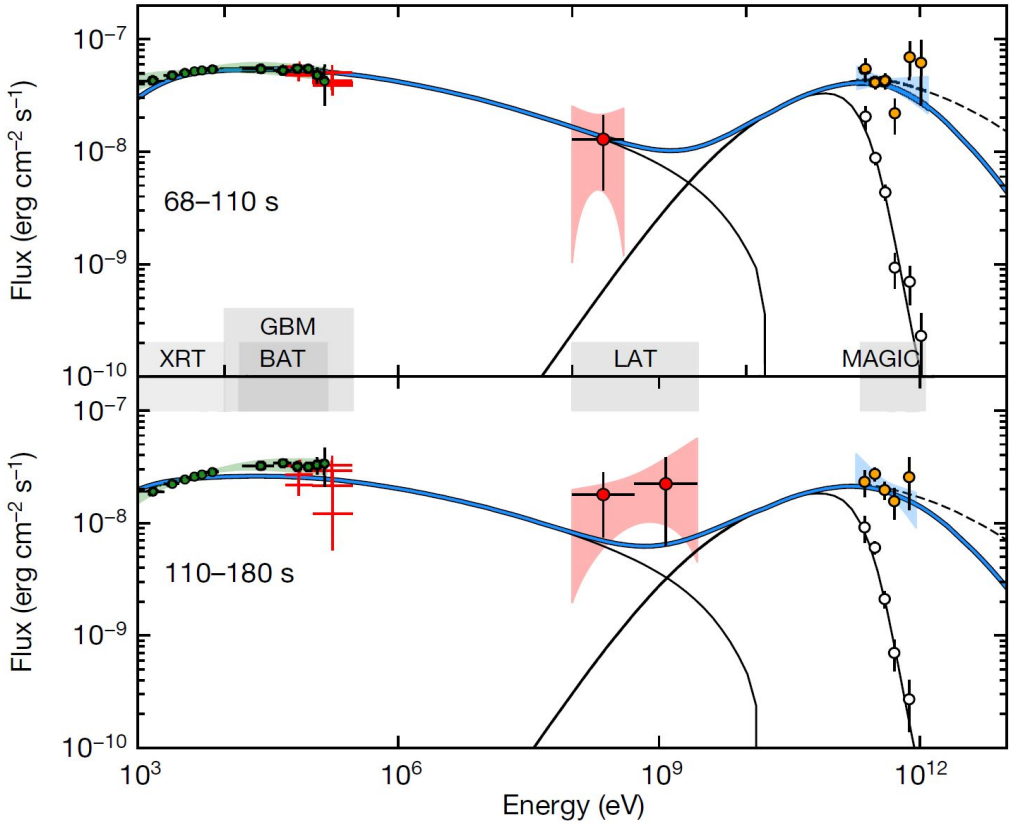
GRB 190114C: photons energy as a function of time



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!

Contributions of GRB 190114C to GRB physics

- Many key question now have (partial) answers:
  - do GRBs emit at VHE? ✓ GRB 190114C does not seem to be particularly special, good indication that VHE emission can be detected in other GRBs
  - is VHE emission from GRBs common?
    - detection by H.E.S.S. of GRB 180720B (another long bright GRB) and GRB 190829A (a very close, low luminosity GRB); detection of GRB 201216C by MAGIC (long GRB, z=1.1):
    - strong hint of detection by MAGIC for short GRB 160821B and for long GRB 201015A
  - what is the emission process? ✓ SSC emission, at least in GRB 190114C and GRB 180720B, but also proposed for GRB 190829A
  - can this emission process contribute also at lower energies?
    - possible contribution of SSC to lower energy emission in LAT band (~100 MeV-tens of GeV)
  - is there VHE emission in both the prompt and the afterglow?
    - keep following-up as fast as possible!

Contributions of GRB 190114C to GRB physics

- Many key question now have (partial) answers:
  - do GRBs emit at VHE? ✓ GRB 190114C does not seem to be particularly special, good indication that VHE emission can be detected in other GRBs
  - is VHE emission from GRBs common?
    - H.E.S.S. GRBs → check D. Khangulyan's talk
    - GRB 201216C (MAGIC) → check S. Fukami's talk
    - GRB 201015A (MAGIC) → check Y. Suda's talk
    - GRB 160821B (MAGIC) → check K. Noda's poster
    - Not detected GRBs upper limits by MAGIC → check F. Longo's poster
  - what is the emission process? ✓ SSC emission, at least in GRB 190114C and GRB 180720B, but also proposed for GRB 190829A
  - can this emission process contribute also at lower energies?
    - possible contribution of SSC to lower energy emission in LAT band (~100 MeV-tens of GeV)
  - is there VHE emission in both the prompt and the afterglow?
    - keep following-up as fast as possible!

Perspectives for GRB follow-ups at VHE

- The VHE era of GRBs has just started, expect more GRB detections in the coming years!
- Interesting results for short GRBs (e.g. GRB 160821B): looking forward to more GW BNS/NSBH events in O4!
- Trying to catch the prompt/early afterglow: fast slewing is possible, we just need a long enough prompt
- New physics studies with GRBs, especially if at high redshift
  - example: LIV limits with GRB 190114C (check G. D'Amico's talk)
- Looking forward to more detections and more surprises!