Observation of sub-TeV gamma-ray emission from GRB 201216C at redshift 1.1

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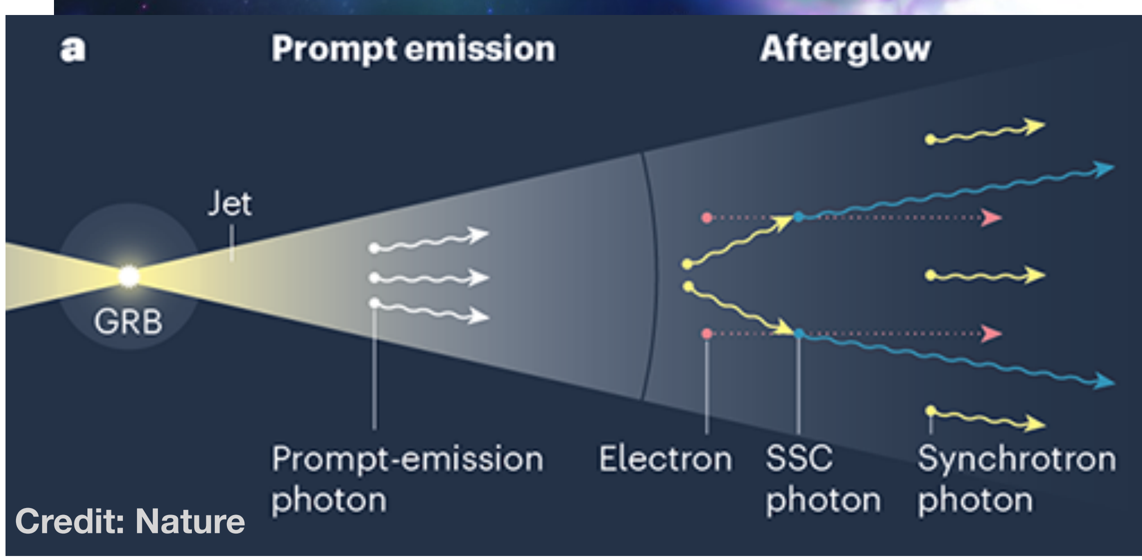
HIROSHIMA

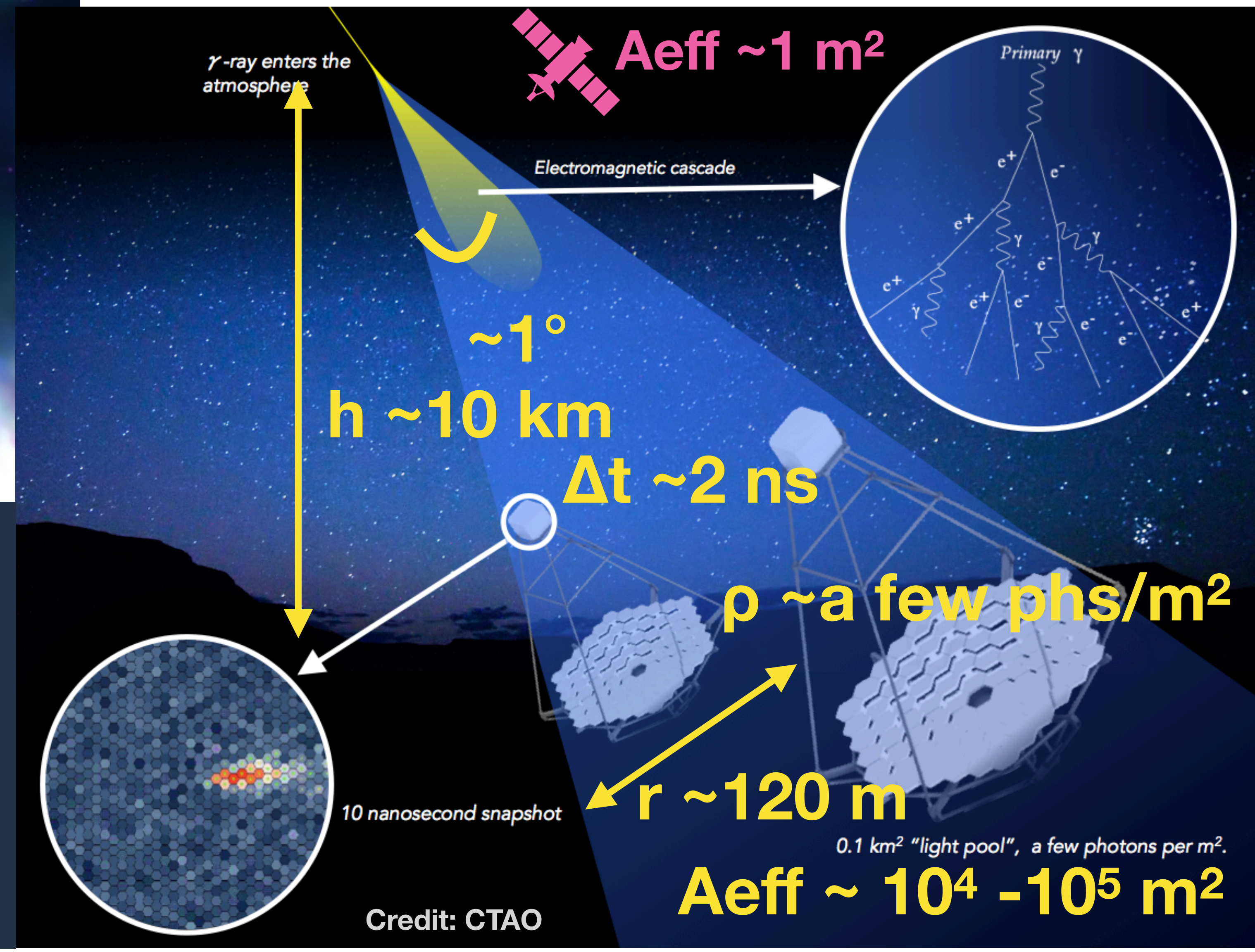
MAGIC

TeVPA 2023

TeV GRBs



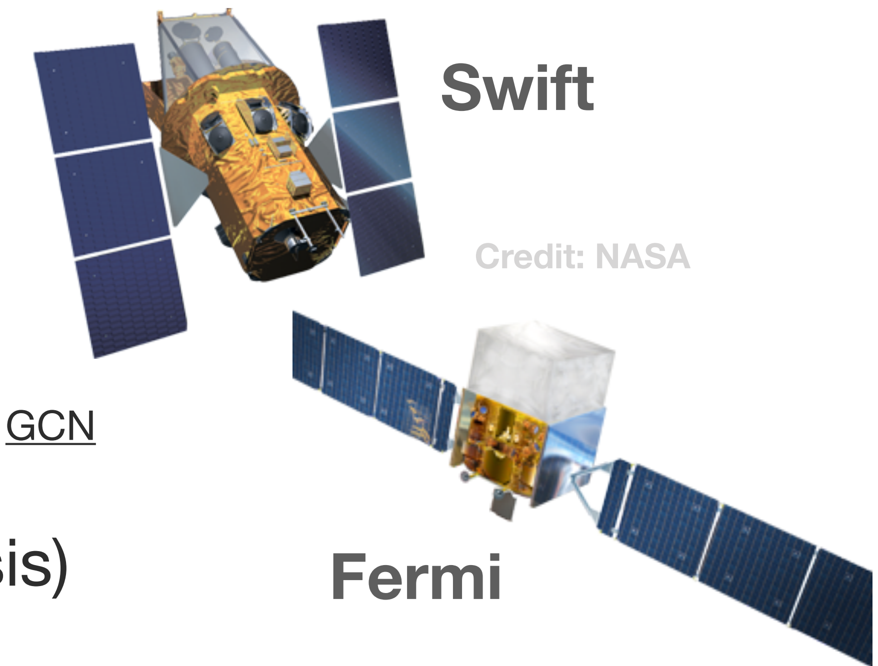
Imaging Atmospheric Cherenkov Telescopes (IACTs)

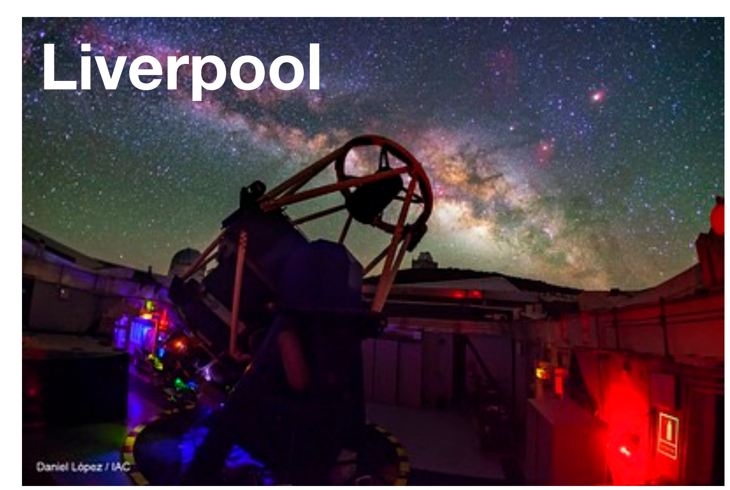


- At least some GRBs are powerful enough to shine the sky with blue-ish flash lights
- Synchrotron self-Compton (SSC) by relativistic electrons in the forward shock is considered to be a straightforward explanation for such TeV emissions
- Need more TeV detections (+MWL data) to deepen our understanding of GRBs

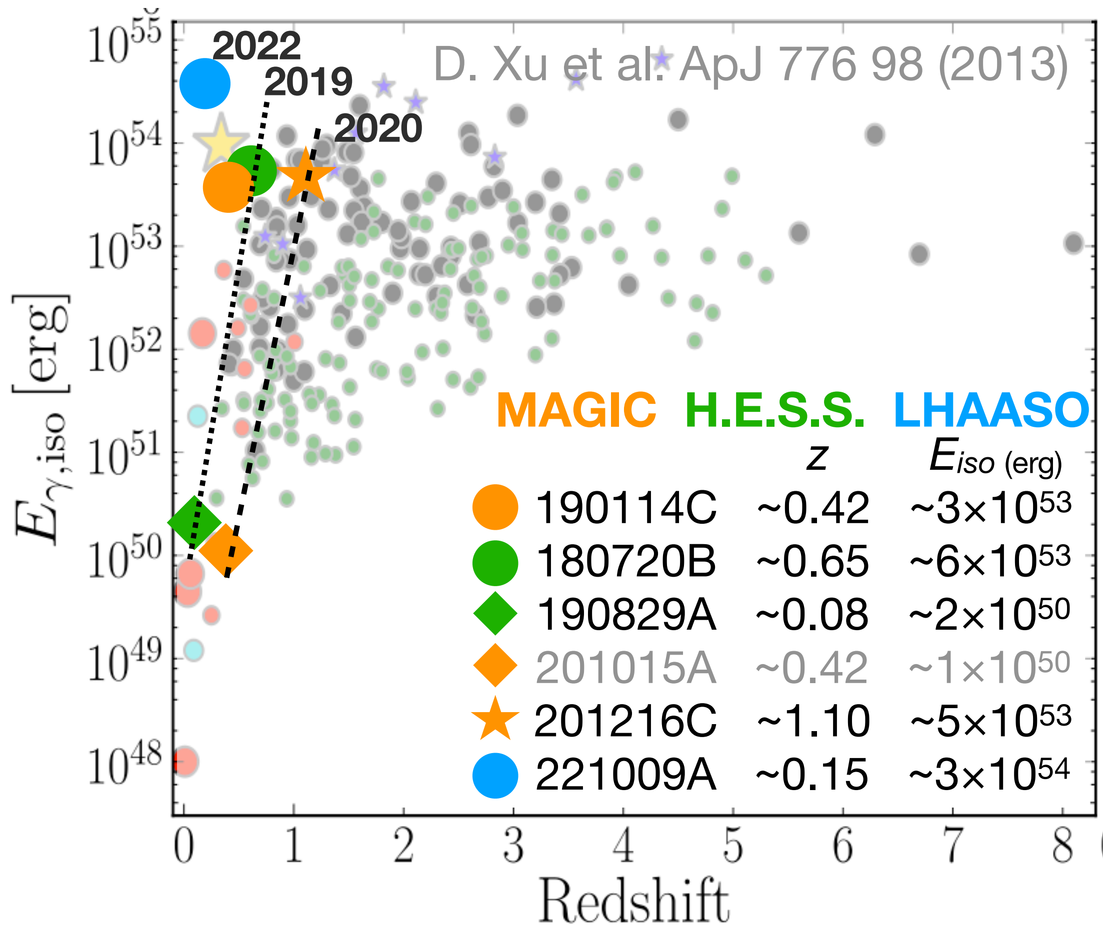
GRB 201216C

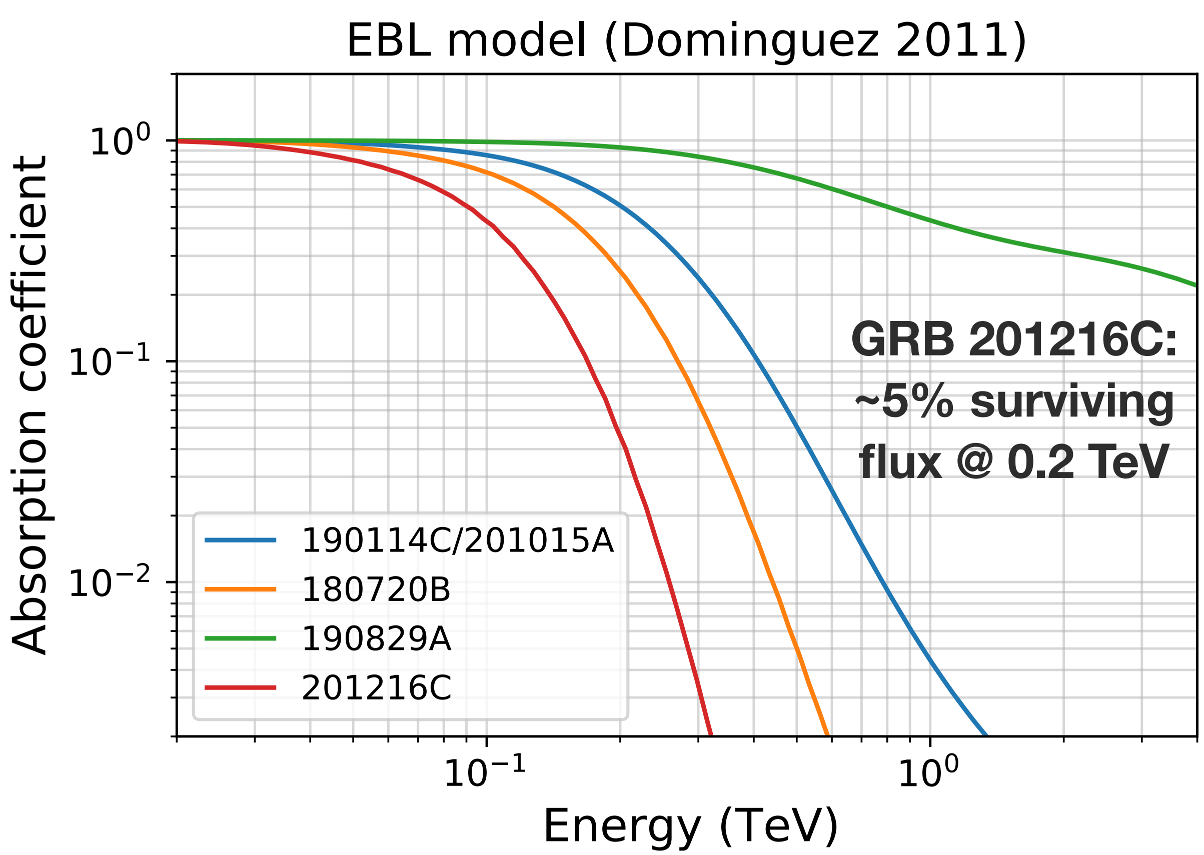
- Bright long GRB triggered by Swift-BAT
  - T_{90} = 48 ±16 s (Swift-BAT, 15-350 keV) GCN 29080
  - z = 1.1 (VLT) GCN 29077
  - E_{iso} = (4.71 ± 0.16)×10^{53} erg (Fermi-GBM, 10-1000 keV) GCN 29077
- Sub-TeV detection by MAGIC: > 5σ detection (quick analysis) → ATel & GCN
- Optical detection
  - Liverpool Telescope: Stable flux from T_0+178 s - T_0+~400 s
  - VLT: Smaller flux at T_0+2.4 h
  - FRAM-ORM: Early-time detection after T_0+31.6 s
- X-ray detection by Swift-XRT from T_0+3 ks
- Radio detection > T_0+5 days (e-MERLIN, VLA, and MeerKAT from Rhodes et al. 2022)
- No detection in UV (UVOT), GeV (Fermi-LAT), sub-PeV (HAWC)





energetic, but a little far

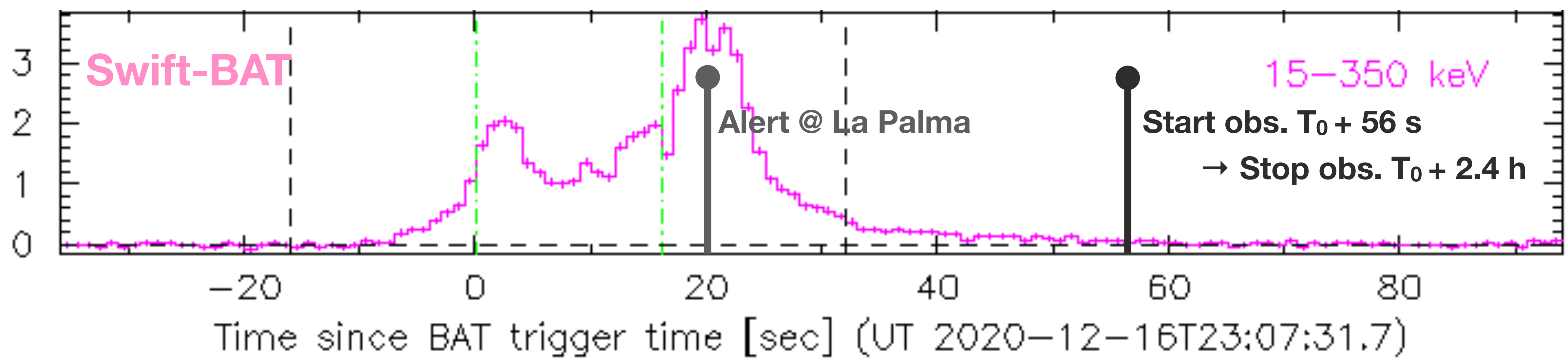




- GRB 201216C has a similar E_{iso} as previously detected TeV GRBs (190114C and 180720B), but the redshift is much larger
- Significant gamma-ray absorption by EBL makes GRB 201216C a challenging object for IACTs

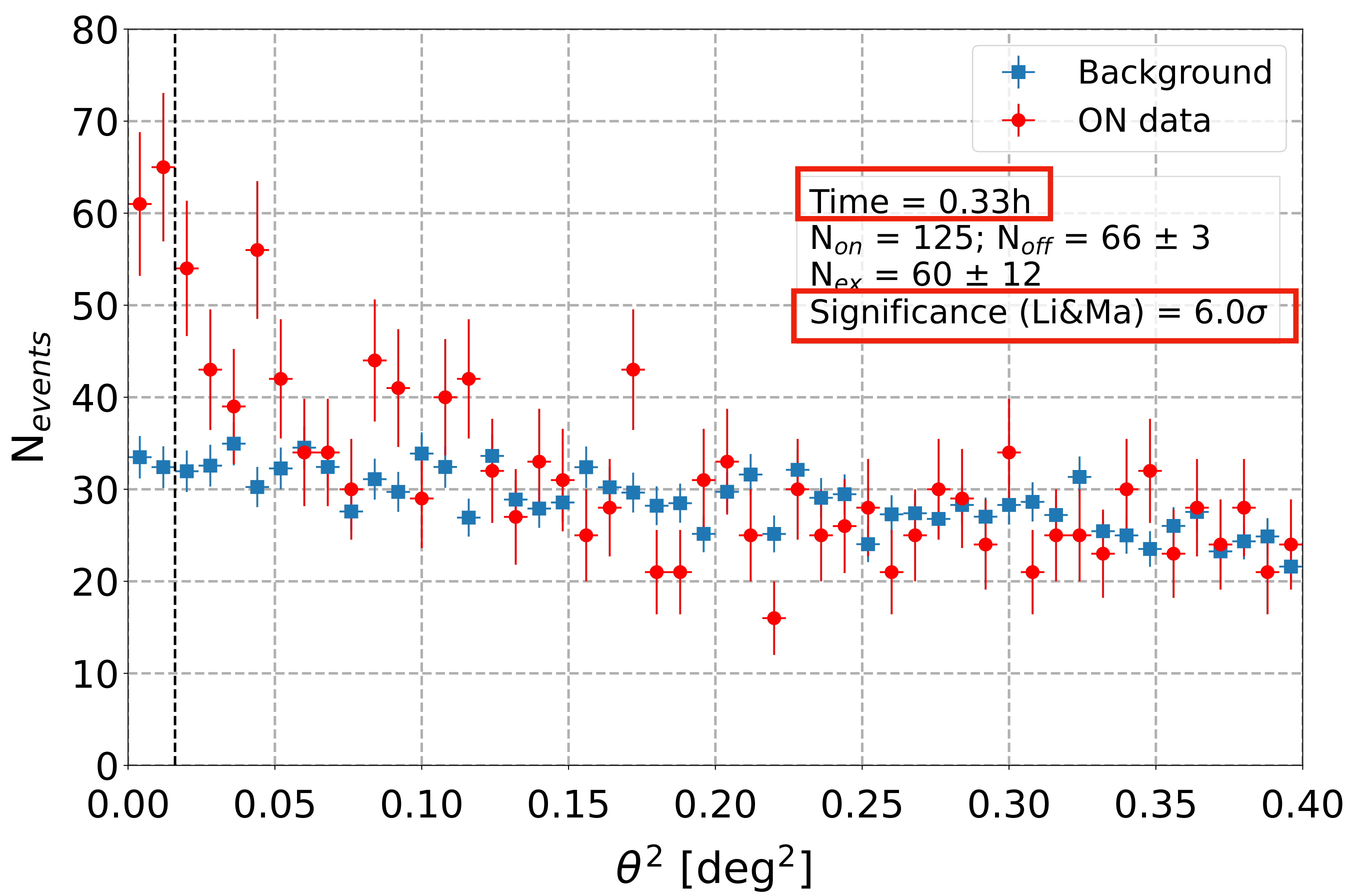
MAGIC observations

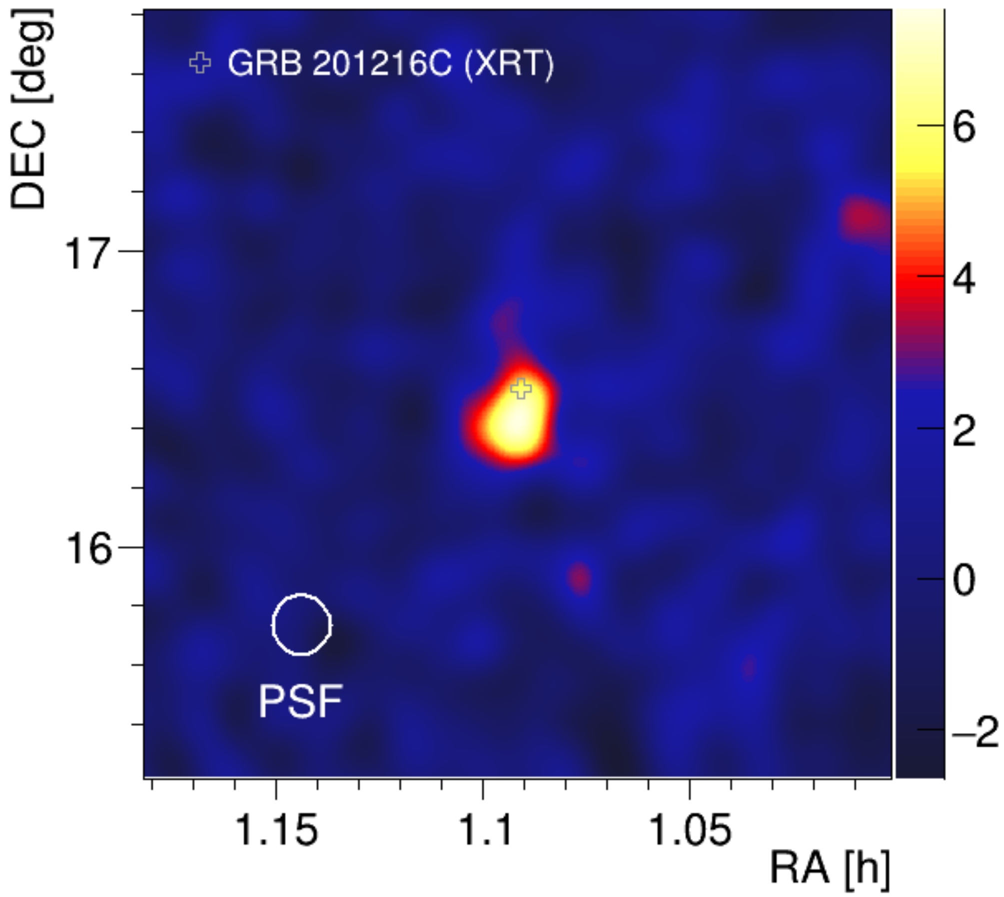
https://gcn.gsfc.nasa.gov/notices_s/1013243/BA



- Thanks to the **fast repointing** capability of MAGIC, we could start observations 36 seconds after the alert arrived (T_0+56 s)
- Zenith angle ranges: (1st night) 37 → 68 deg, (2nd night) 17 → 46 deg
- Dark time (no moon)
- Good weather condition (LIDAR transmission > 0.9 at 9 km both nights)
- MAGIC **low energy analysis** method applied

Significance of sub-TeV emission

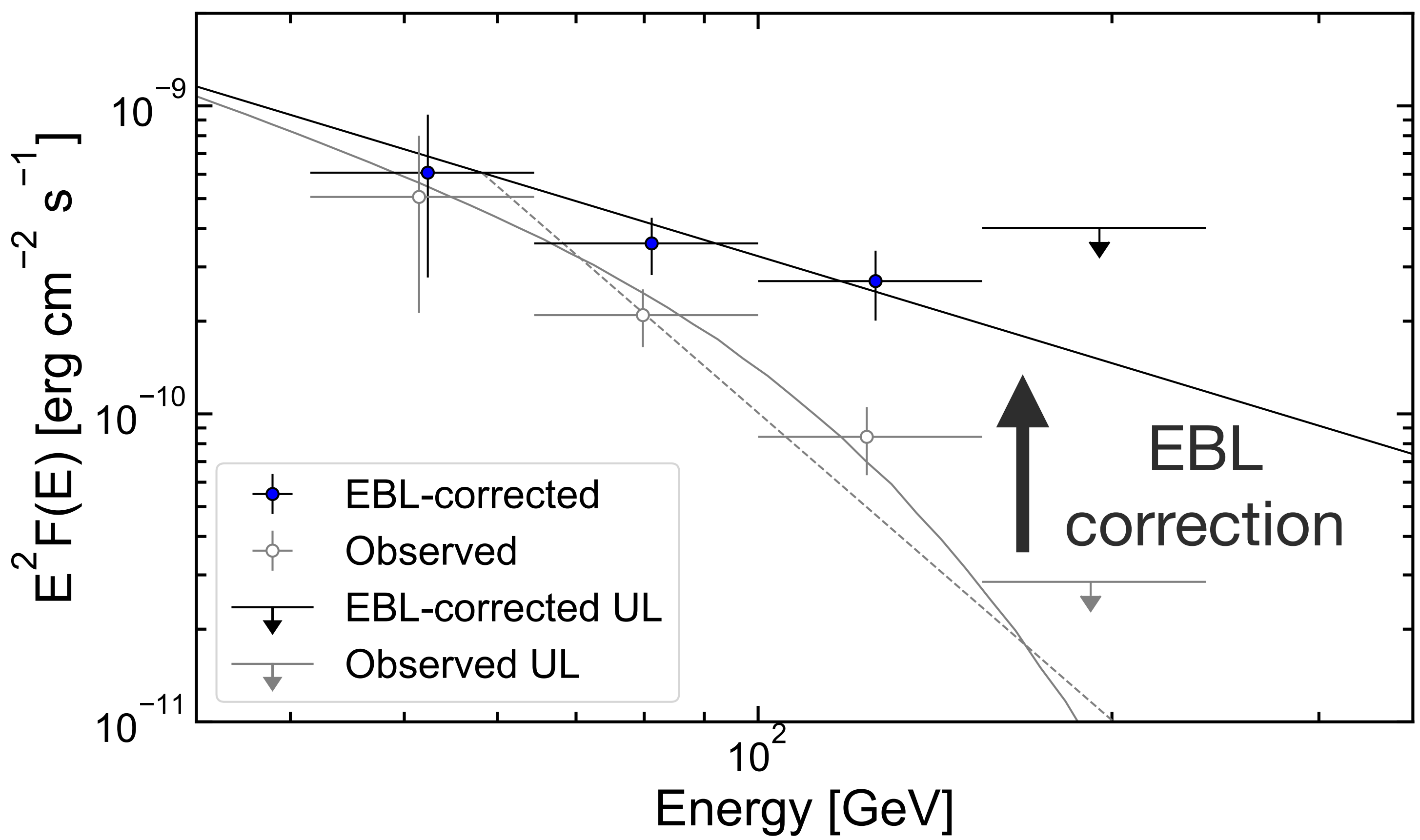




- Optimized event cuts using simulated data with a power-law index of -2
- θ^2 plot: 6.0 σ significance (Li&Ma) in the first 20 min of observations
- Skymap: > 6 σ hotspot close to the GRB position by Swift-XRT
- GRB 201216C is the **farthest IACT source** so far

SED in sub-TeV regime

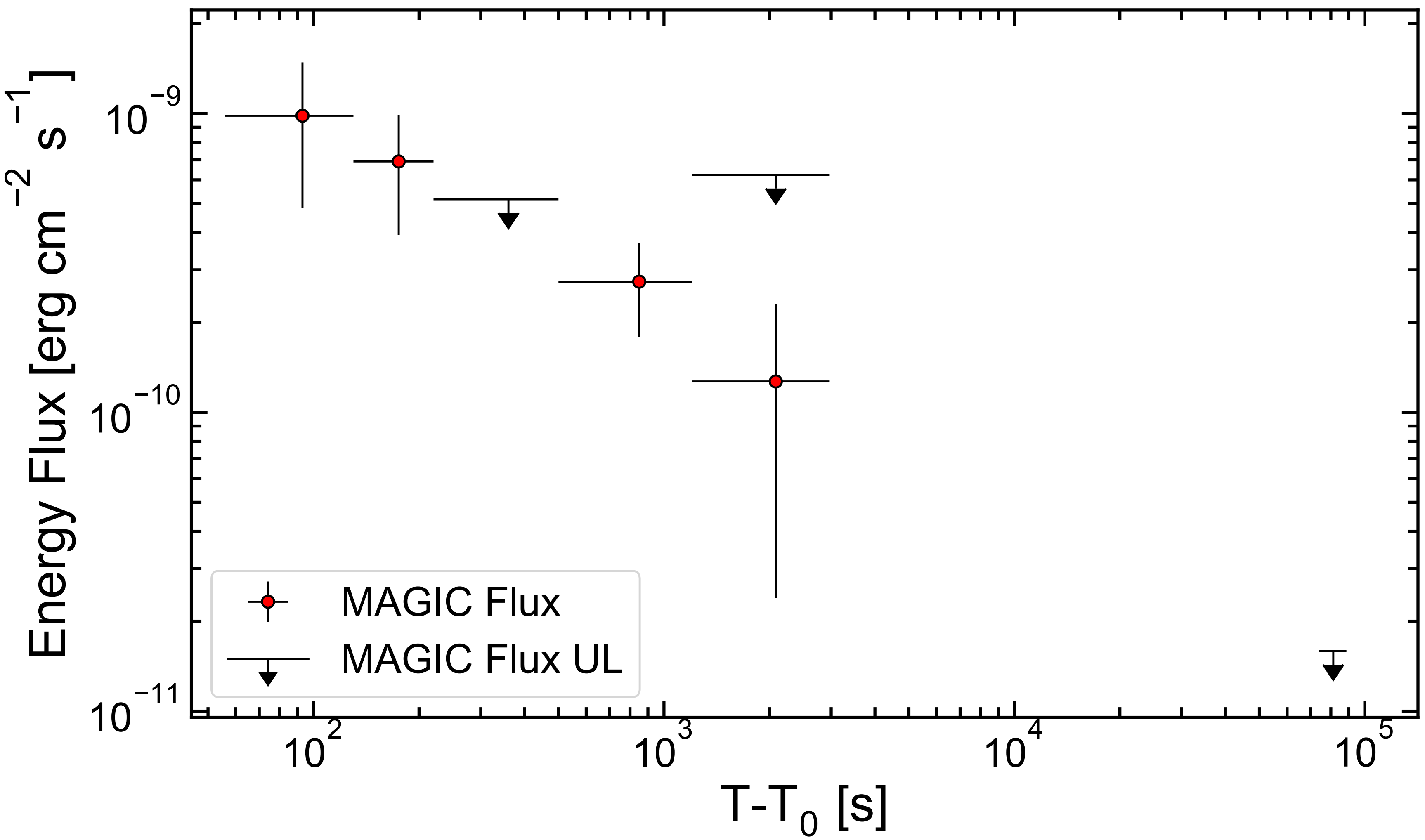
- **Observed** spectrum has a steep power-law index of **-5.32±0.53** (stat.)
- **Intrinsic** spectrum is consistent with a power-law function whose index is **-3.15±0.70** (stat.)
- Systematic errors on the energy-scale/EBL models are larger than statistical errors due to the steep spectrum/high redshift



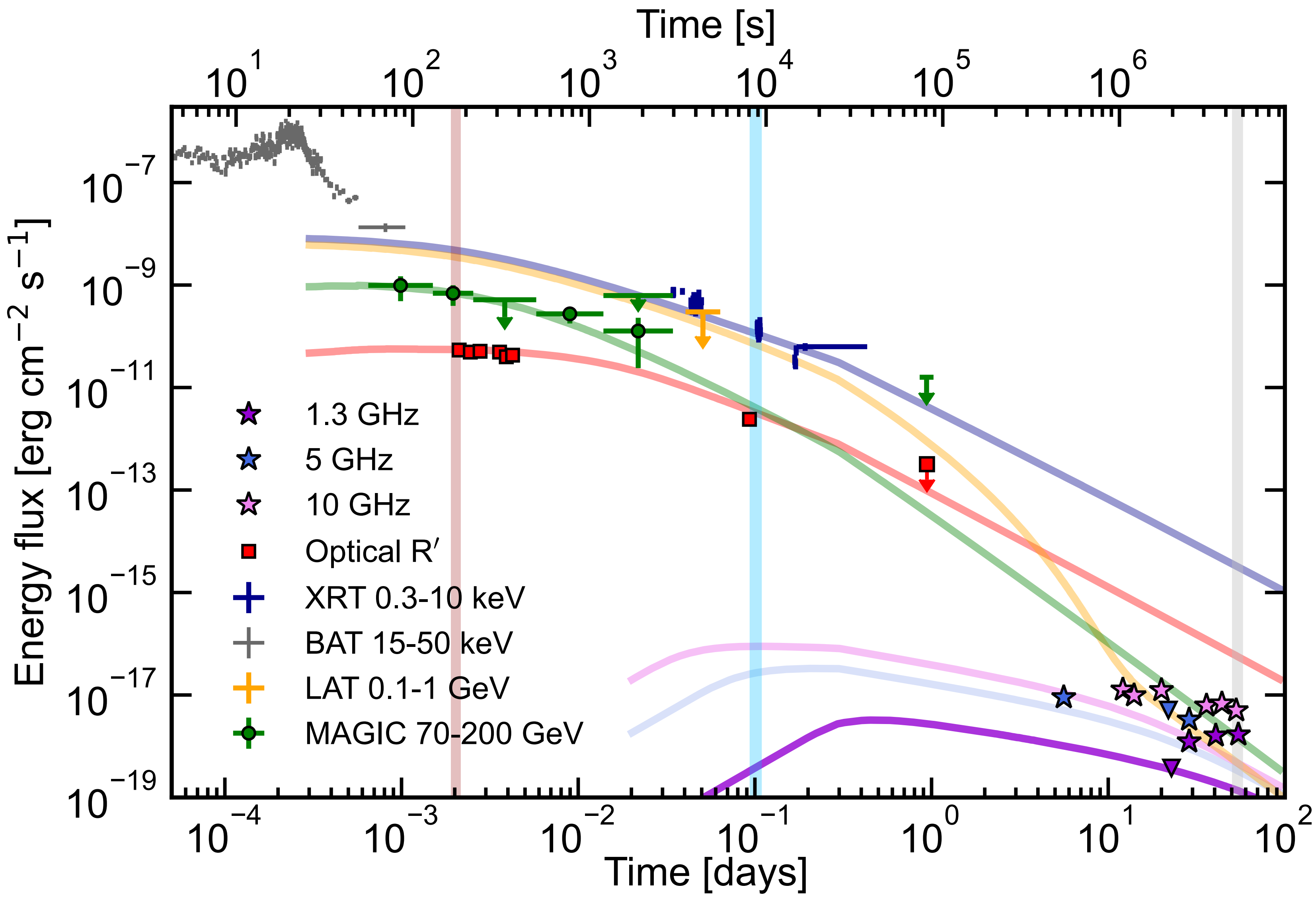
light scale	EBL	normalization [TeV^{-1} cm^{-2} s^{-1}]	index
nominal	D11	$(2.03 \pm 0.39) \times 10^{-8}$	-3.15 ± 0.70
-15%	D11	$(1.14 \pm 0.25) \times 10^{-8}$	-3.19 ± 0.52
+15%	D11	$(2.99 \pm 0.53) \times 10^{-8}$	-2.17 ± 0.57
nominal	F08	$(1.95 \pm 0.38) \times 10^{-8}$	-3.19 ± 0.70
nominal	FI10	$(2.76 \pm 0.54) \times 10^{-8}$	-2.65 ± 0.73
nominal	G12	$(3.99 \pm 0.77) \times 10^{-8}$	-2.45 ± 0.71

Sub-TeV light curve

- EBL-corrected energy-flux light curve in 70 GeV - 200 GeV
  - 1st night: T_0+56 s to T_0+40 min
  - 2nd night: T_0+20.5 h to T_0+24.6 h
  - Upper limits calculated as 95% C.L. for the bins with relative errors > 50%
- Compatible with a power-law decay. Best fit index (until 5th bin) is **-0.62±0.04**

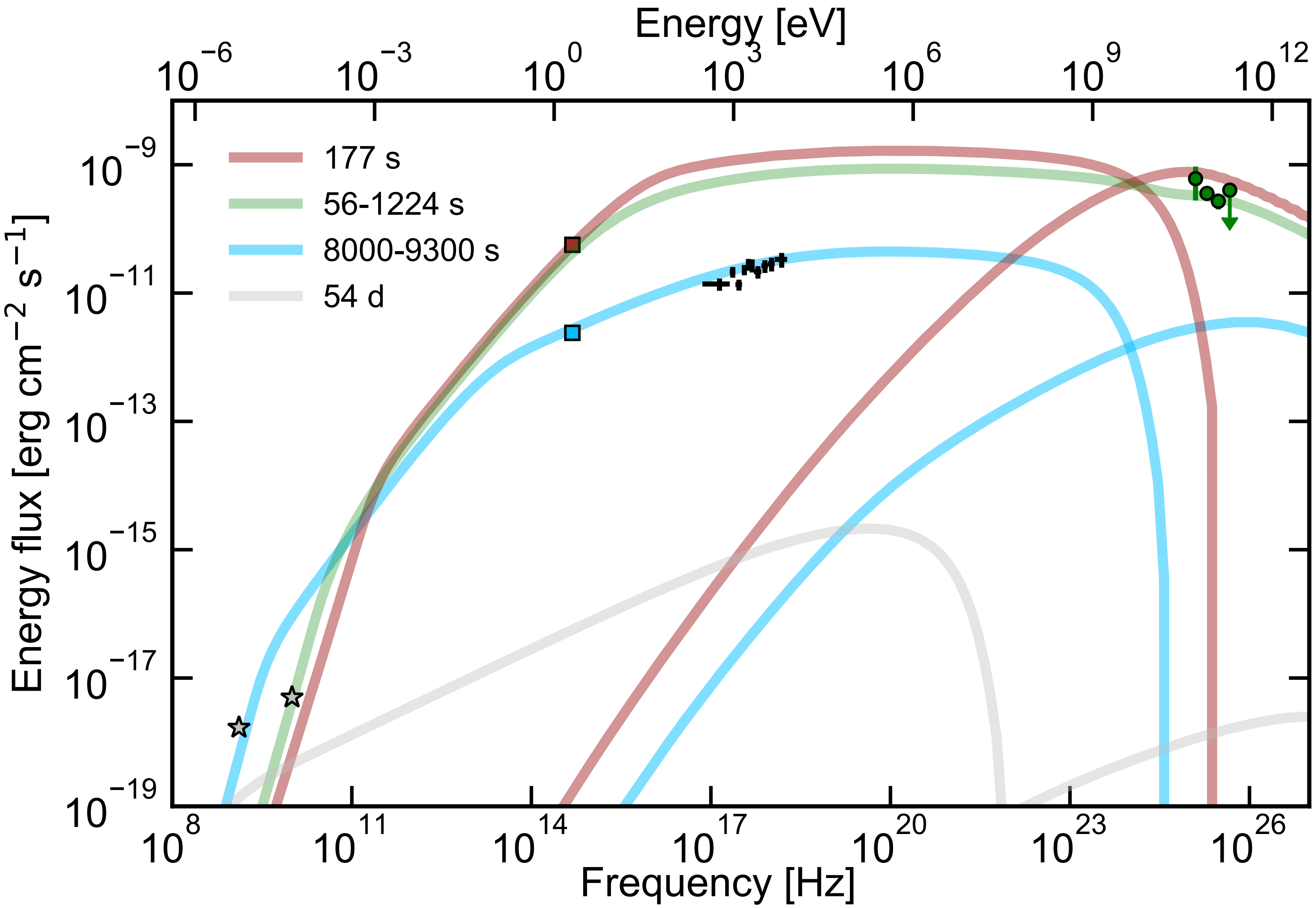


MWL light curves



- Strong suggestion of wind-like density profile (by Granot&Sari 2002)
  - Plateau in optical flux up to T_0+~400 s
  - No increase in sub-TeV flux at the deceleration phase
- Indication of another component for radio emission

MWL SEDs



Best-fit parameters

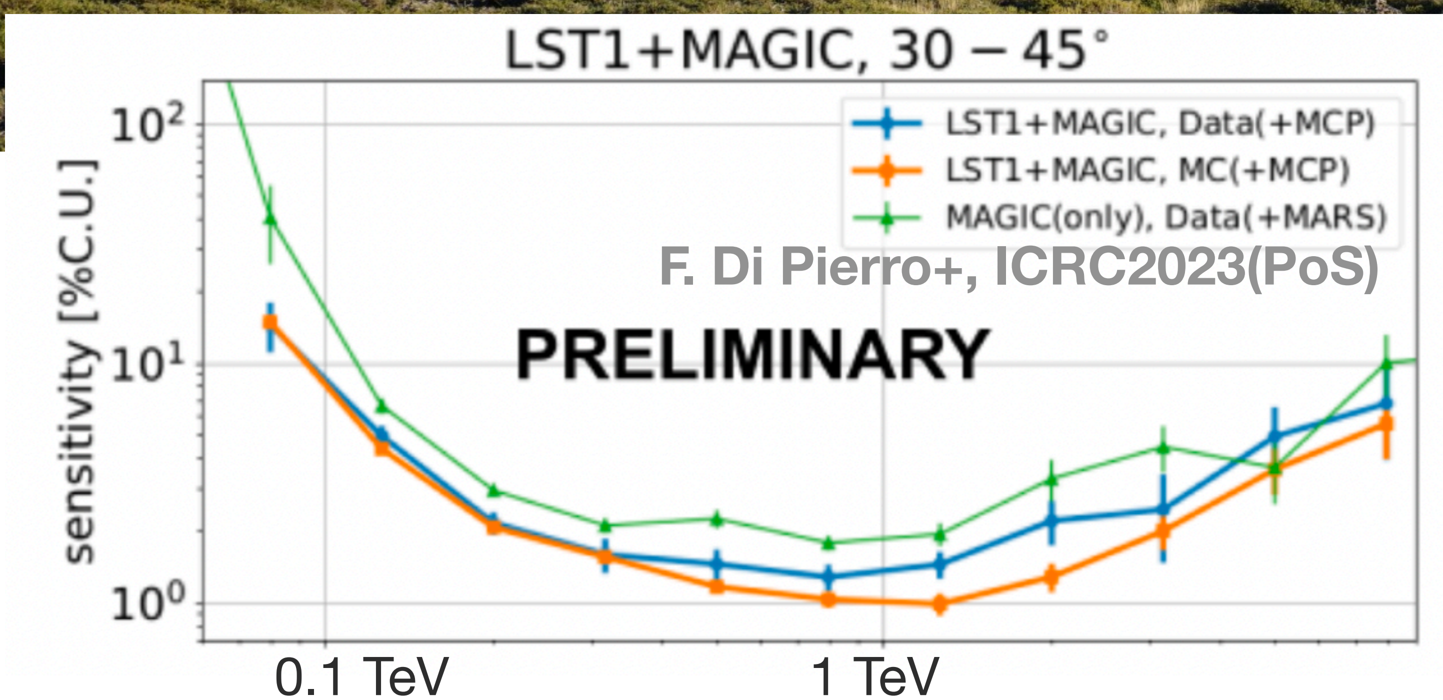
$E_k = 4 \times 10^{53}$ erg
$\theta_{jet} = 1°$
$\Gamma_0 = 180$
$n(R) = 7.5 \times 10^{33}\ R^{-2}\ \mathrm{cm}^{-1}$
$p = 2.1$
$\varepsilon_e = 0.08$
$\varepsilon_B = 2.5 \times 10^{-3}$

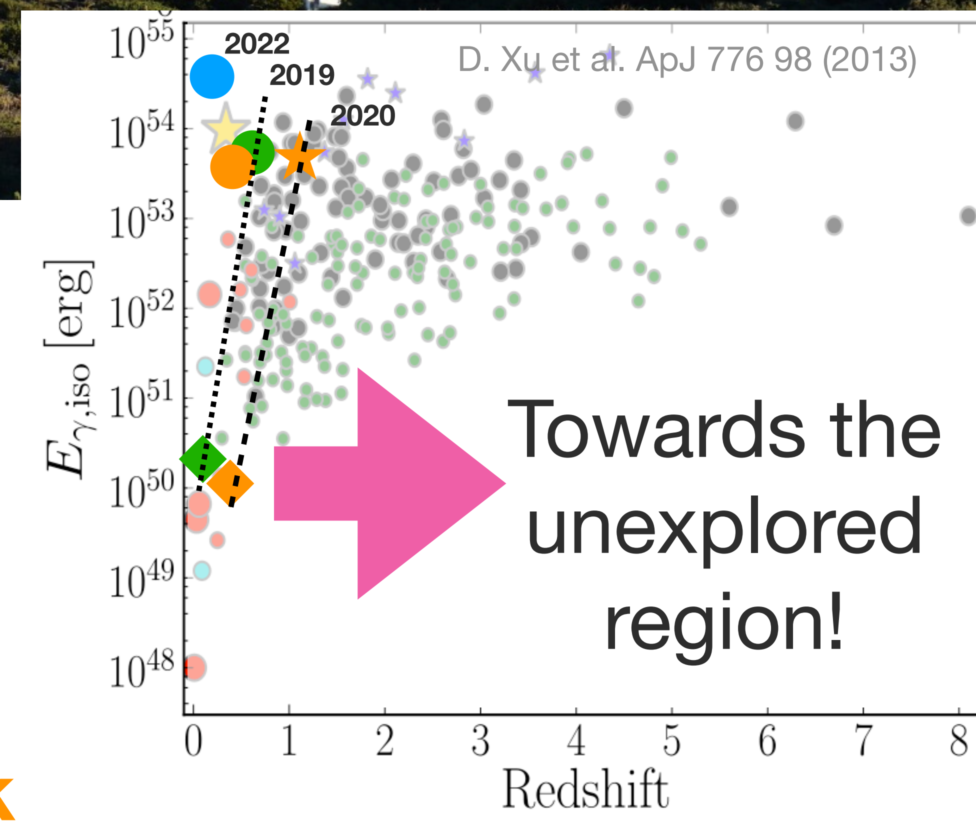
- MWL fluxes are consistent with the synchrotron+SSC model (Miceli&Nava 2022)
  - Sub-TeV emission is well above the maximum synchrotron energy (~10 GeV at T_0+~177 s)
  - No solution found with a homogeneous density medium

Summary

- GRB 201216C is a bright long GRB at z = 1.1
- Thanks to both the fast repointing and low energy capability of the MAGIC telescopes, the sub-TeV emission was detected at 6 σ level
- The sub-TeV spectrum and light curve are consistent with power-laws
- Both observations and modeling support a wind-like medium
- The synchrotron+SSC one-zone model can explain the MWL data except for the radio one, which requires modification on the simple model
- Paper is being reviewed by the journal. Stay tuned!

Improving our eyesight





See A. Berti talk

- We are ready to catch more TeV GRBs together with CTA LST-1!