VERY HIGH ENERGY EMISSION IN GAMMA-RAY BURSTS

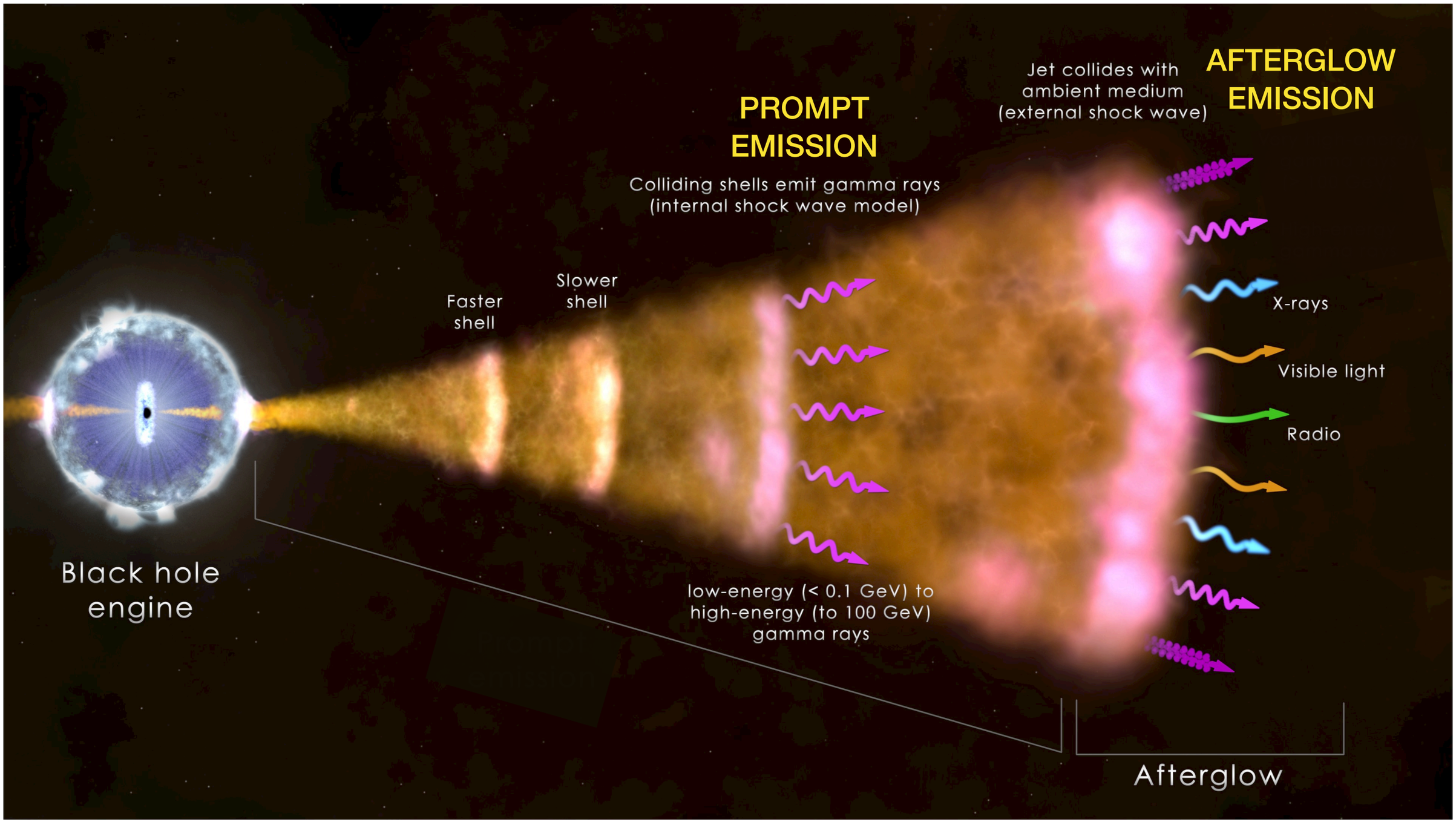
Lara Nava

INAF

Osservatorio Astronomico di Brera

Gamma-Ray Bursts (GRB)

The general picture



Prompt emission

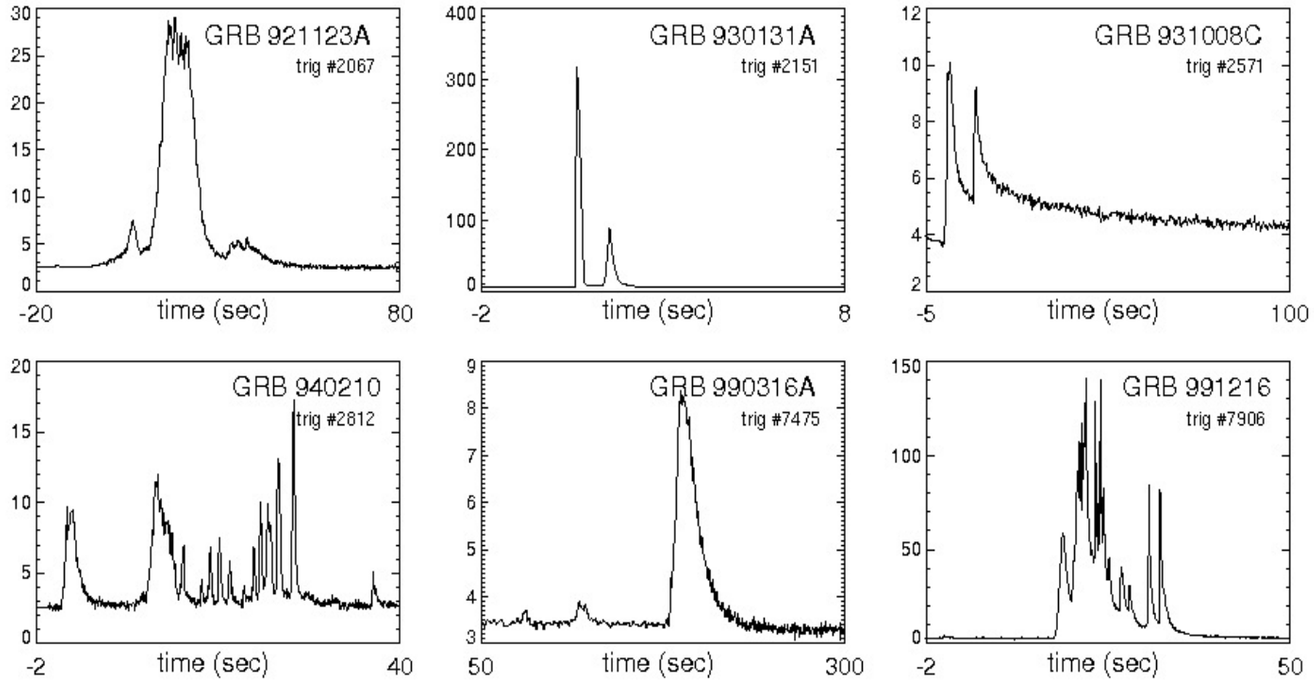
OBSERVATIONS

- keV - MeV
- Non-thermal
- One single spectral component

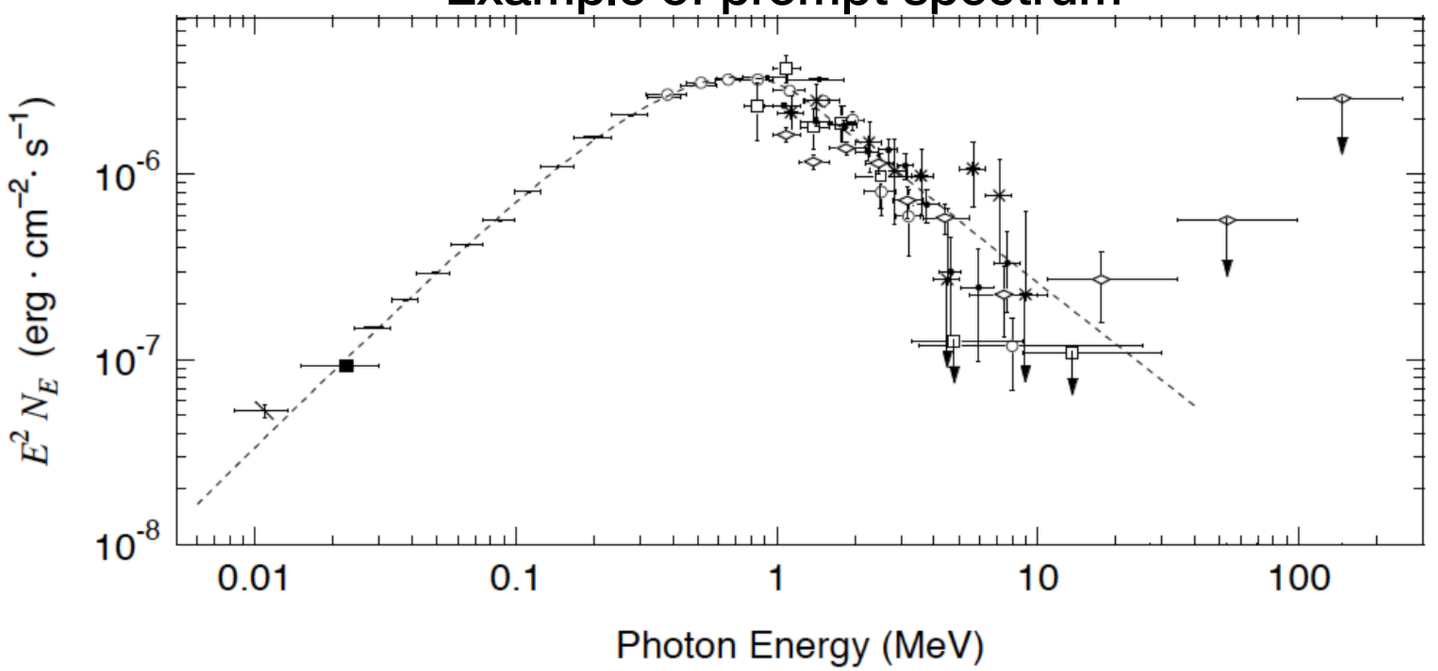
OPEN ISSUES

- Radiative mechanism
- Dissipation mechanism
- Nature of variability
- Properties at the emitting region

Examples of prompt light-curves

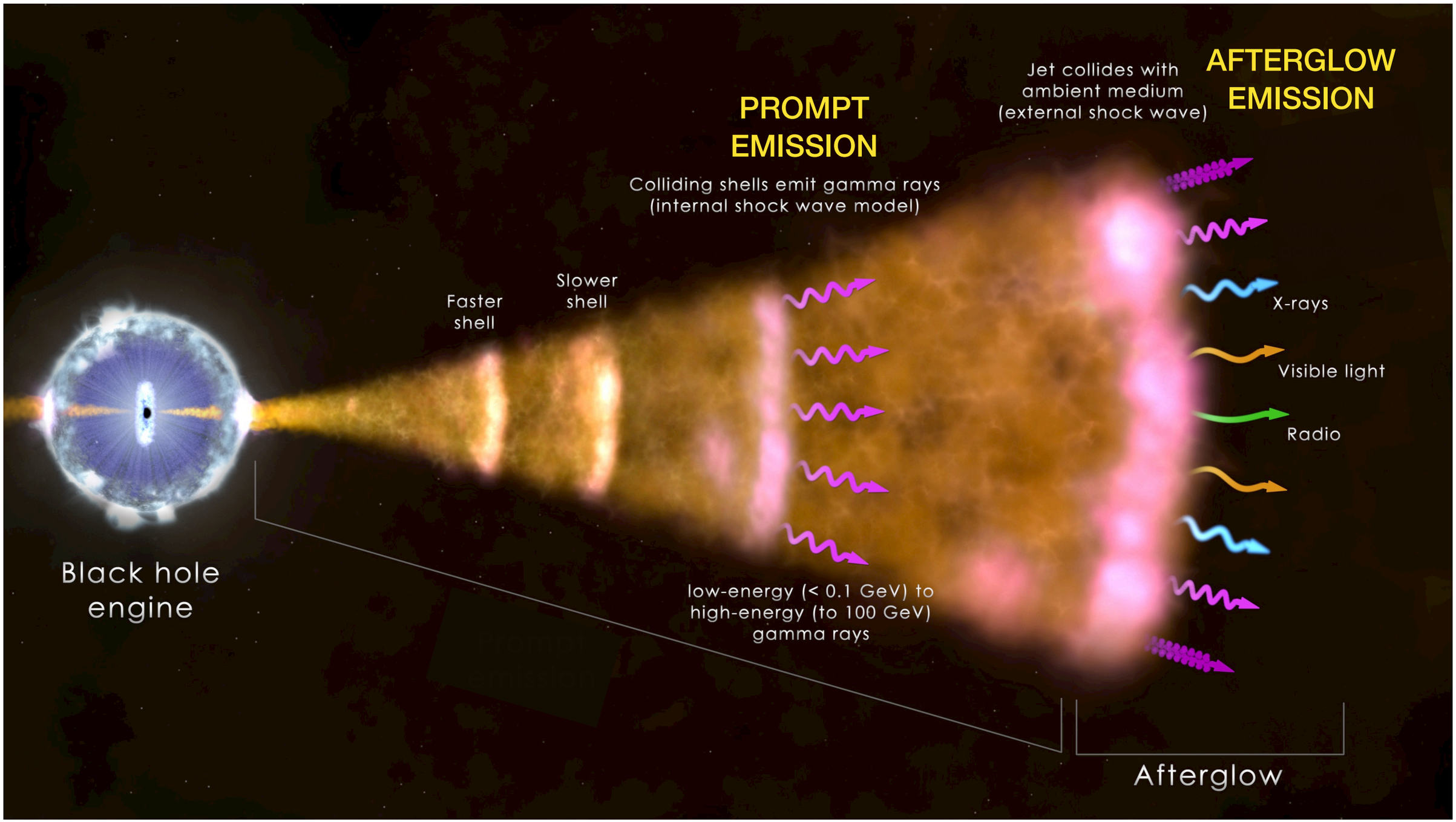


Example of prompt spectrum



Gamma-Ray Bursts (GRB)

The general picture



Afterglow emission

OBSERVATIONS

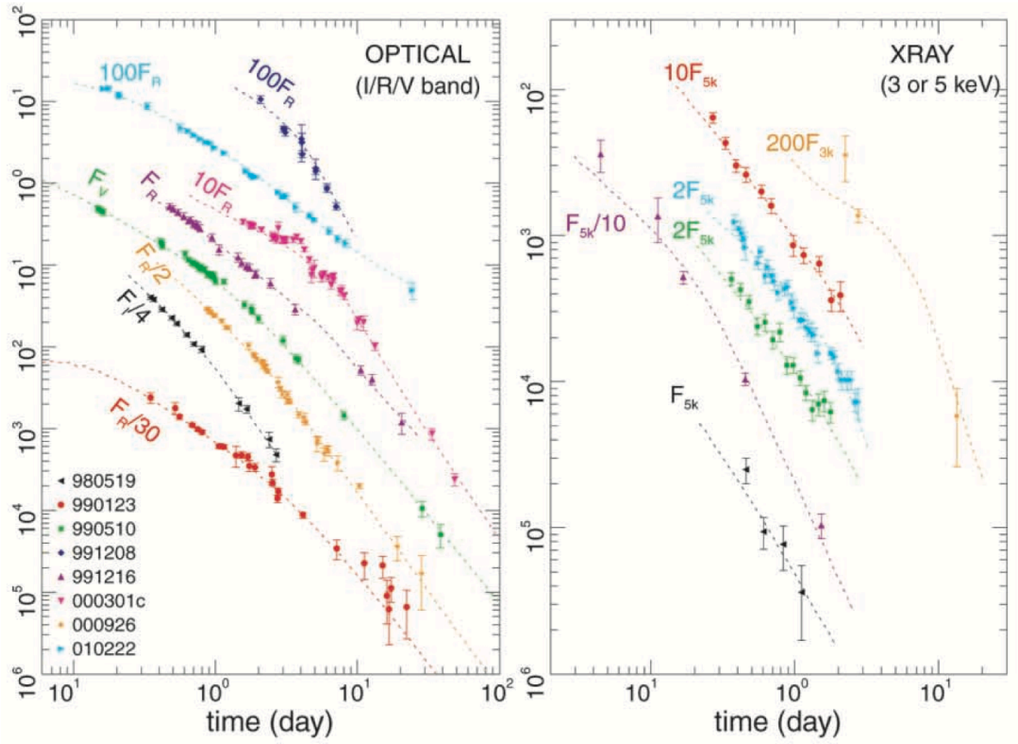
- Longer duration
- smooth light-curves (PL decay)
- Soft X-ray to radio
- GeV

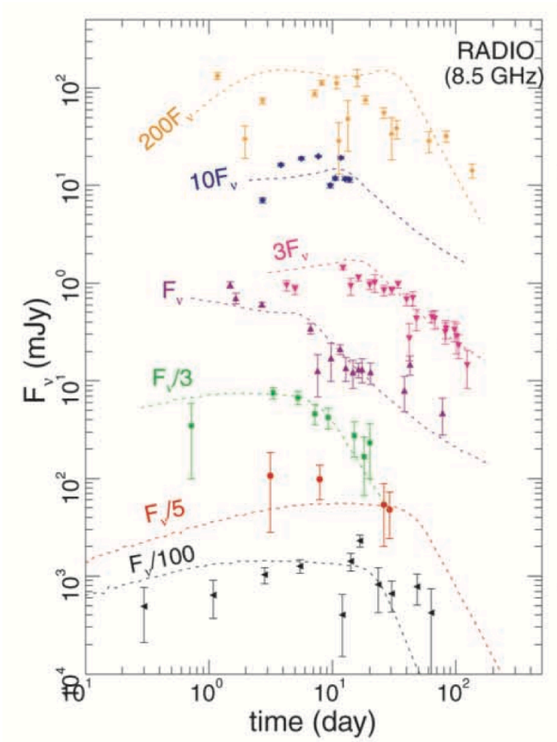
INTERPRETATION

- Mostly synchrotron from electrons at forward shock

LIMITATIONS

- Large degeneracies among model parameters:
  - Jet energy and Lorentz factor
  - Environment
  - particle acceleration





Panaitescu & Kumar 2001

Observations at VHE (>0.1TeV)

STATUS

- Eluded IACTs (Imaging Atmospheric Cherenkov Telescopes) for many years
- Until 2019 unclear if GRBs are VHE emitters
- Not robust predictions from theory
- Since 2019: 5 detections

RELEVANCE OF VHE OBSERVATIONS

- Prompt: understand nature of radiative mechanism
- Afterglow: place further constraints on model parameters
- EBL, LIV, IGMF, …

TeV detections by IACTs

A summary

Miceli D. & Nava L., 2022, Galaxies, 10, 66

	T_{90} s	$E_{\gamma,iso}$ erg	z	T_{delay} s	E_{range} TeV	IACT (sign.)
160821B	0.48	1.2×10^{49}	0.162	24	0.5-5	MAGIC (3.1σ)
180720B	48.9	6.0×10^{53}	0.654	3.64×10^{4}	0.1-0.44	H.E.S.S. (5.3σ)
190114C	362	2.5×10^{53}	0.424	57	0.3-1	MAGIC ($> 50\sigma$)
190829A	58.2	2.0×10^{50}	0.079	1.55×10^{4}	0.18-3.3	H.E.S.S. (21.7σ)
201015A	9.78	1.1×10^{50}	0.42	33	0.14	MAGIC (3.5σ)
201216C	48	4.7×10^{53}	1.1	56	0.1	MAGIC (6.0σ)

significance < 5σ

significance > 5σ

TeV detections by IACTs

MAGIC Detection of GRB 190114C

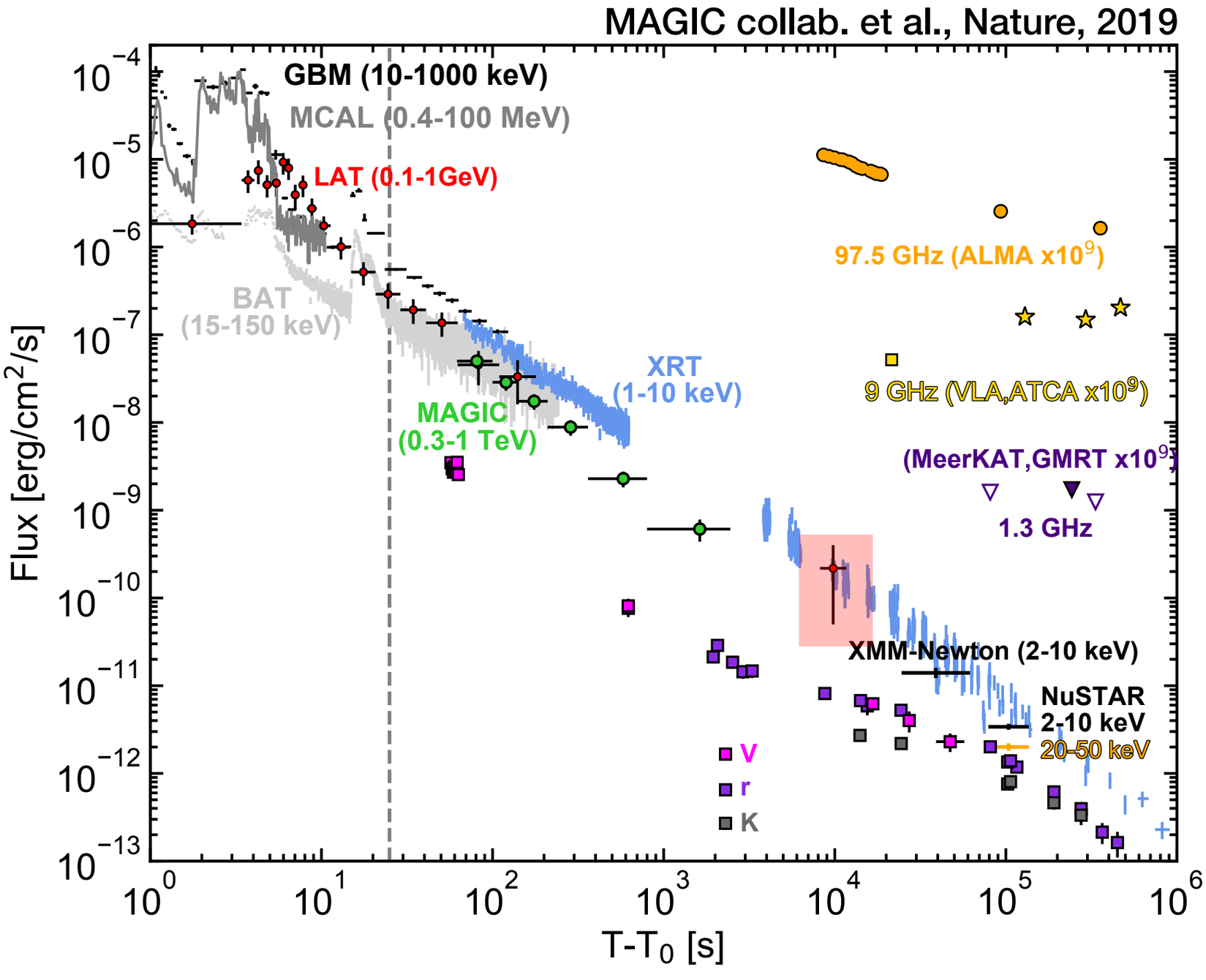
General properties

- Long GRB
- z = 0.42
- $E_{prompt} = 2.5 \times 10^{53}$erg

MAGIC detection

- 1-40 minutes after the GRB
- in the energy range 0.3-1 TeV

MAGIC collab. et al., Nature, 2019



TeV detections by IACTs

MAGIC Detection of GRB 190114C

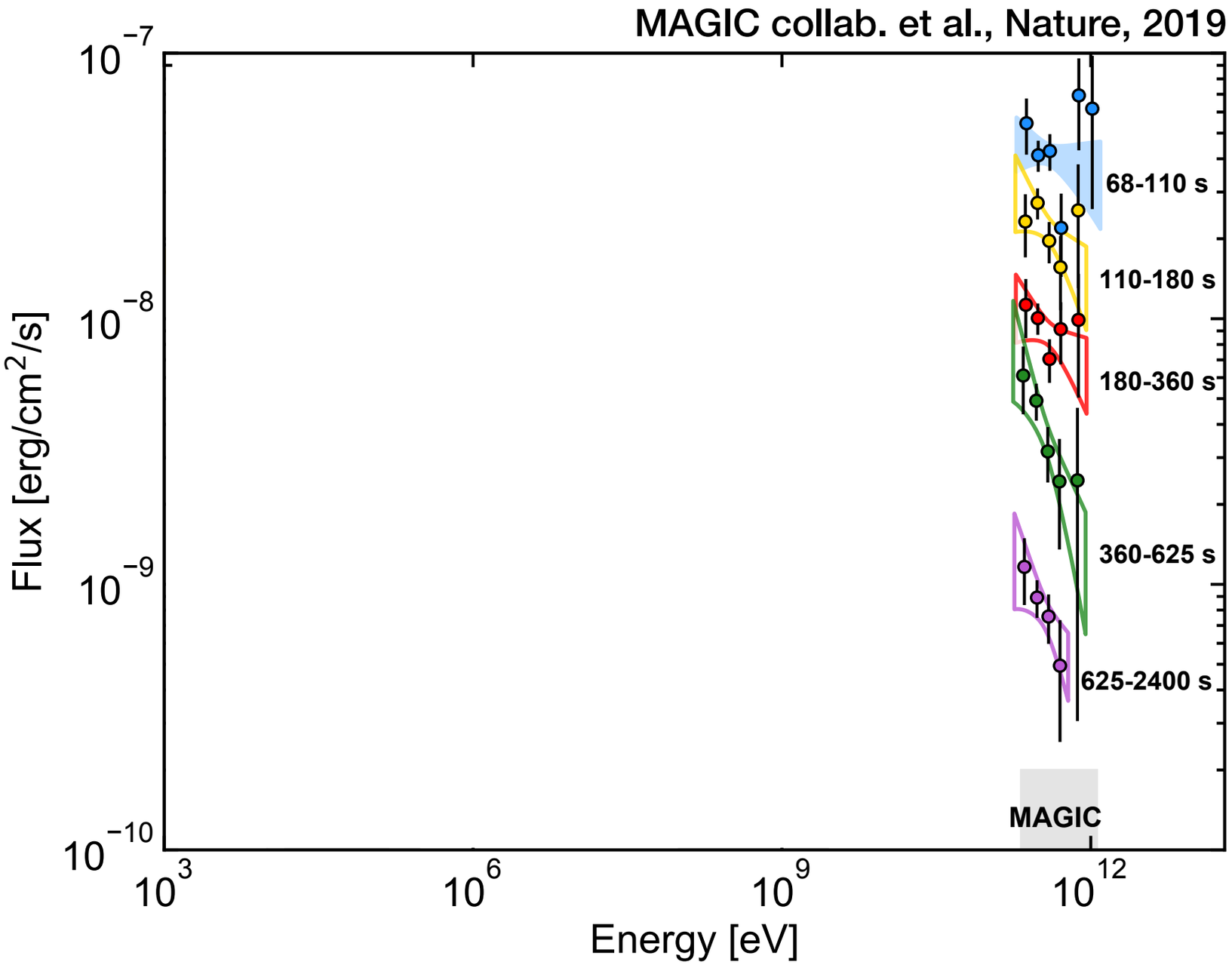
General properties

- Long GRB
- z = 0.42
- $E_{prompt} = 2.5 \times 10^{53}$erg

MAGIC detection

- 1-40 minutes after the GRB
- in the energy range 0.3-1 TeV

MAGIC collab. et al., Nature, 2019



TeV detections by IACTs

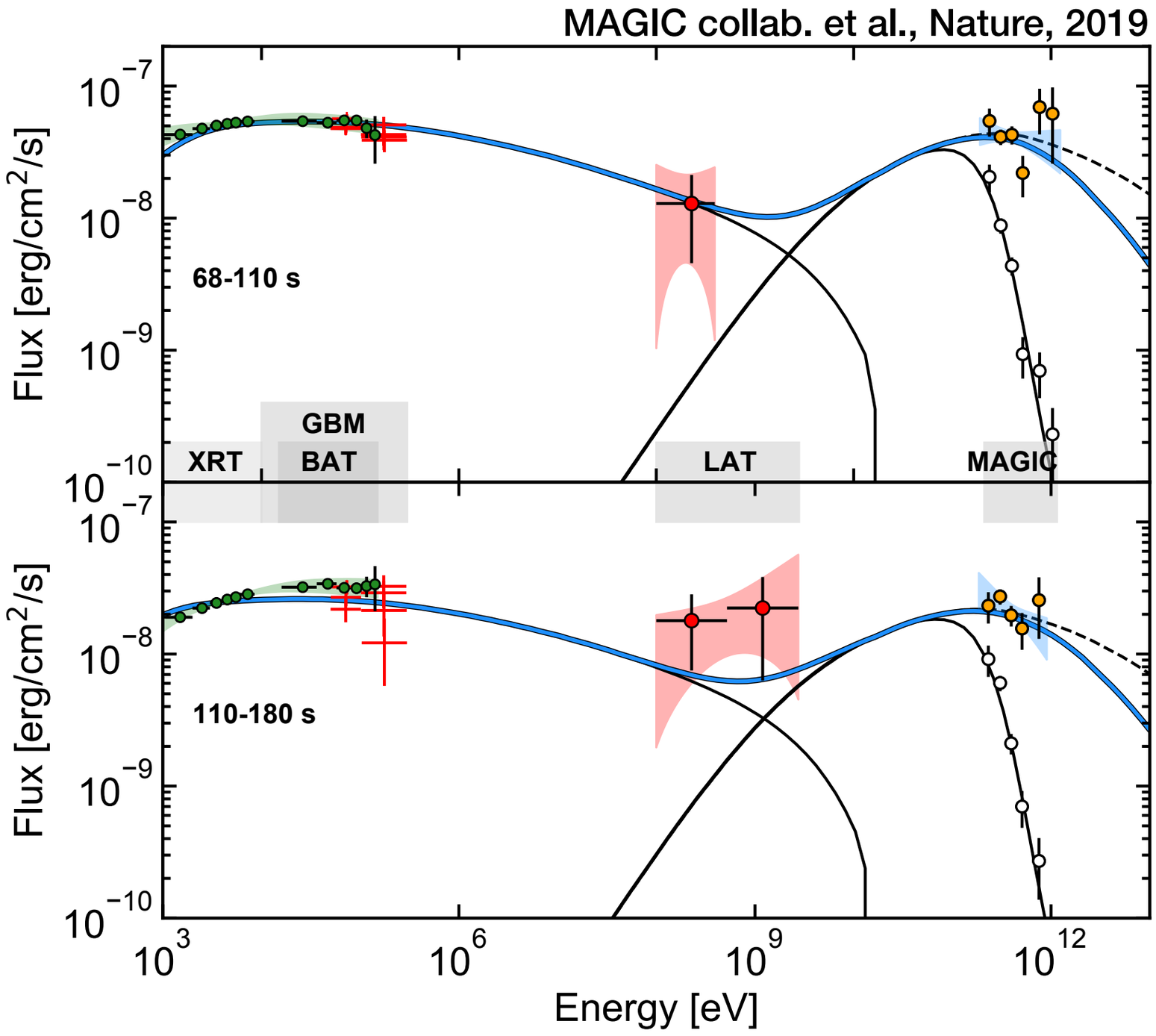
MAGIC Detection of GRB 190114C

General properties

- Long GRB
- z = 0.42
- $E_{prompt} = 2.5 \times 10^{53}$erg

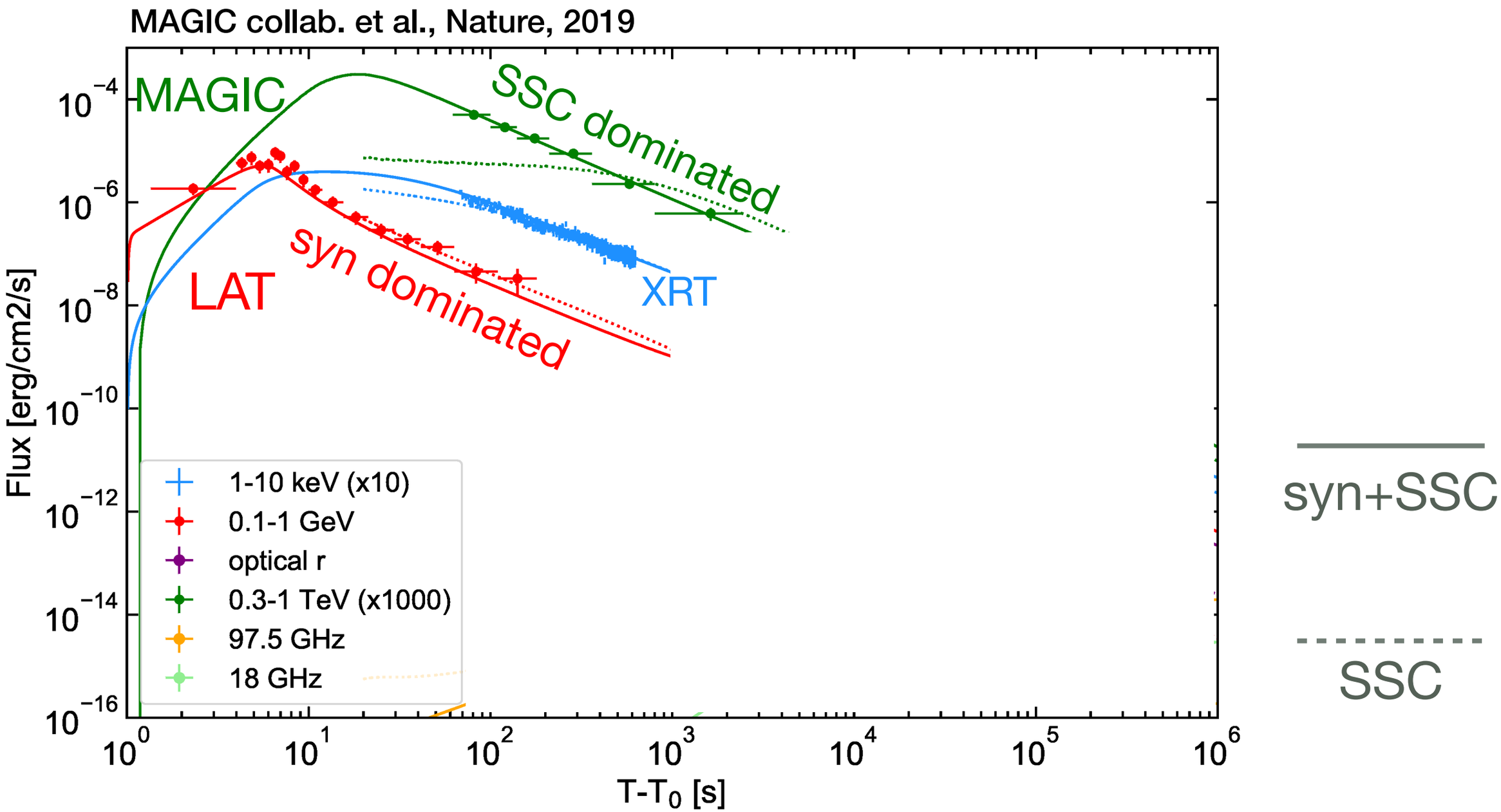
MAGIC detection

- 1-40 minutes after the GRB
- in the energy range 0.3-1 TeV



TeV detections by IACTs

MAGIC Detection of GRB 190114C



$E = 8 \times 10^{53}$ erg $\Gamma = 700$ $s = 0$ $n_0 = 0.5$ cm^{-3}

$\varepsilon_e = 0.07$ $\varepsilon_B = 8 \times 10^{-5}$ $p = 2.6$

TeV detections by IACTs

H.E.S.S. Detection of GRB 180720B

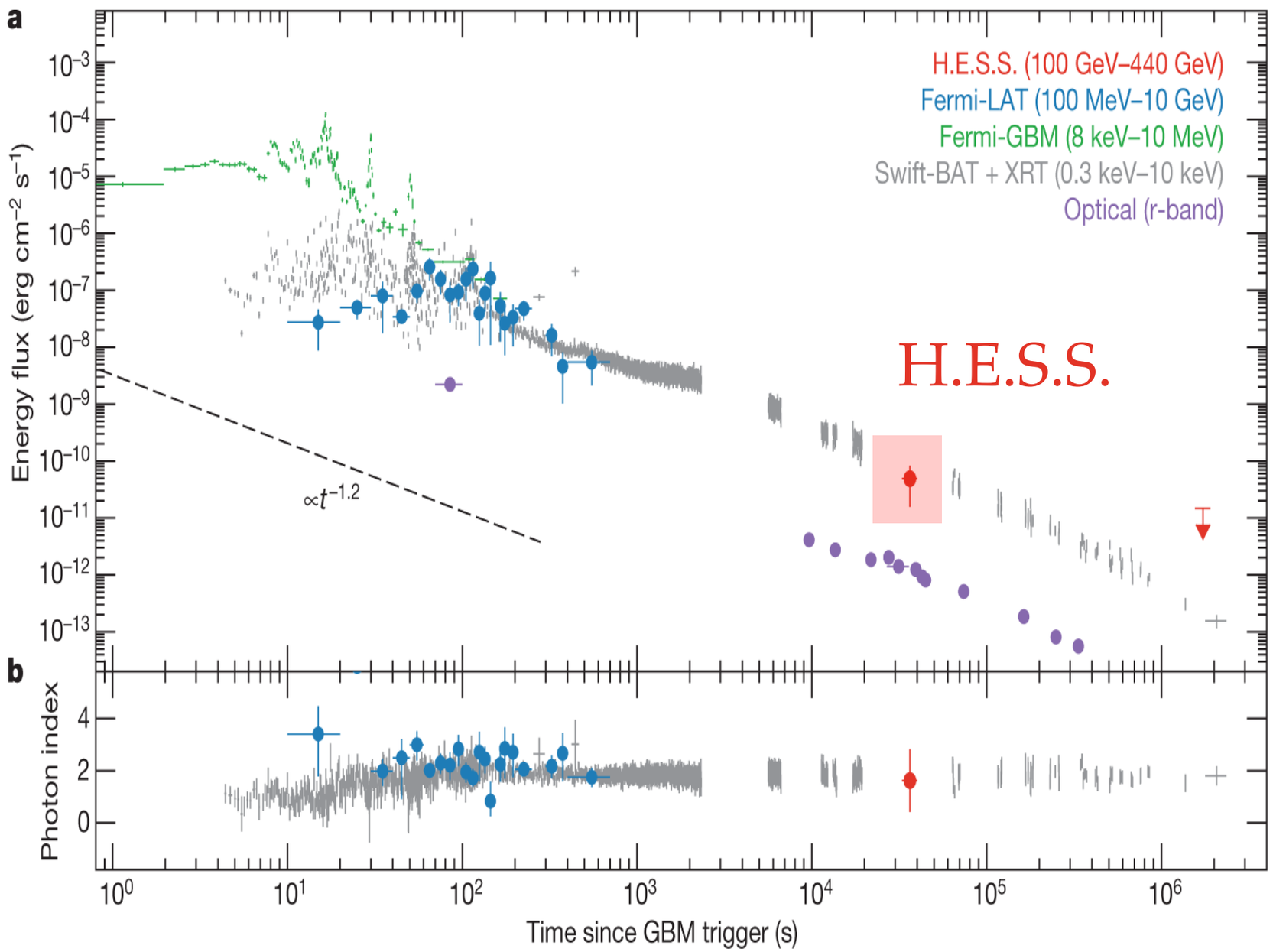
General properties

- Long GRB
- z = 0.65
- E_{prompt} = 6 x 10^{53}erg

HESS detection

- ~10 hours after the GRB
- in the energy range 0.1-0.44 TeV

H.E.S.S. Collab, 2019, Nature, 575, 464



TeV detections by IACTs

H.E.S.S. Detection of GRB 190829A

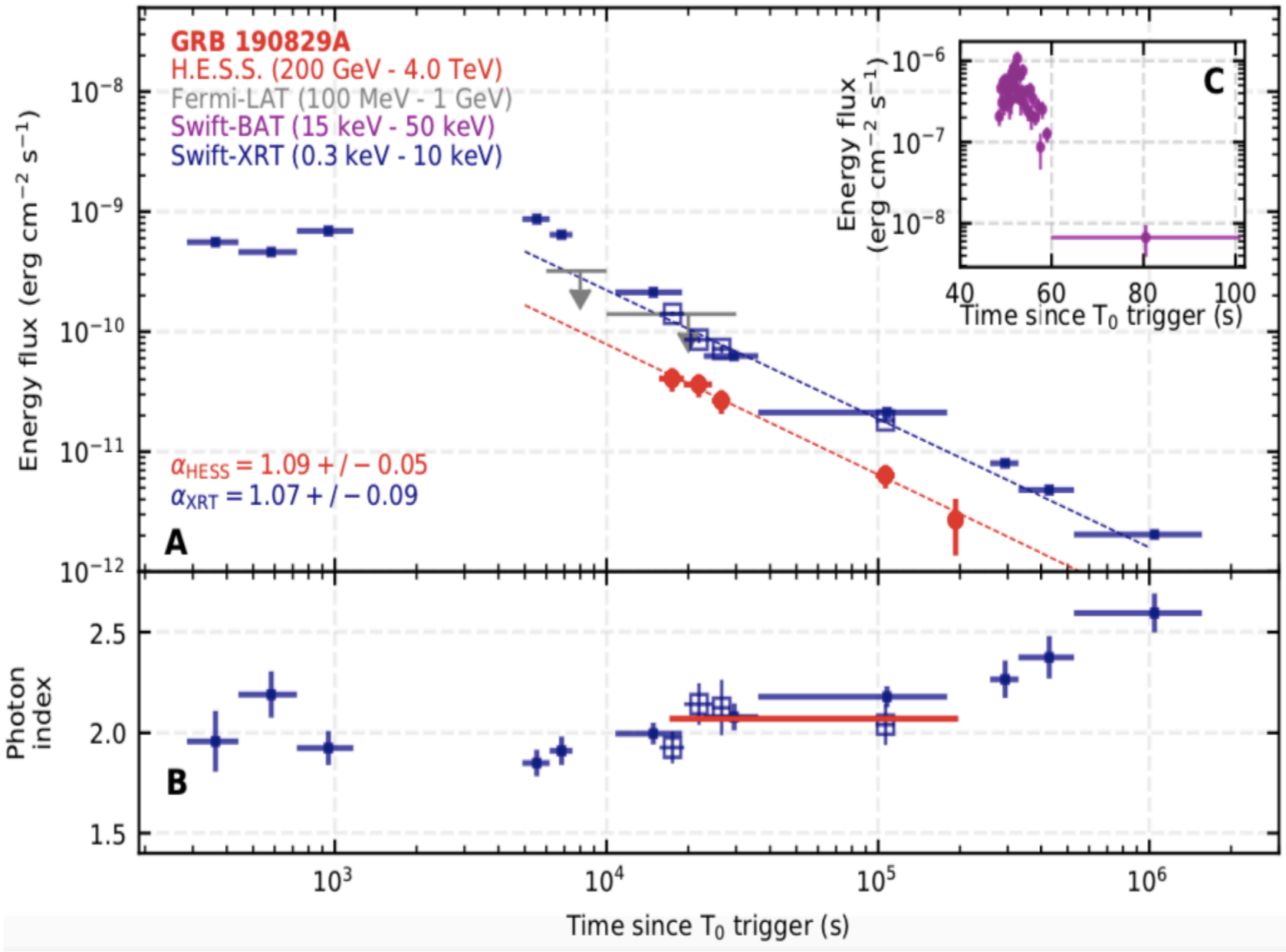
General properties

- Long GRB
- z = 0.079
- E_{prompt} = 2 x 10^{50}erg

HESS detection

- ~4 hours after the GRB
- in the energy range 0.2-3.3 TeV

H.E.S.S. Collab, 2019, Nature, 575, 464



TeV detections by IACTs

H.E.S.S. Detection of GRB 190829A

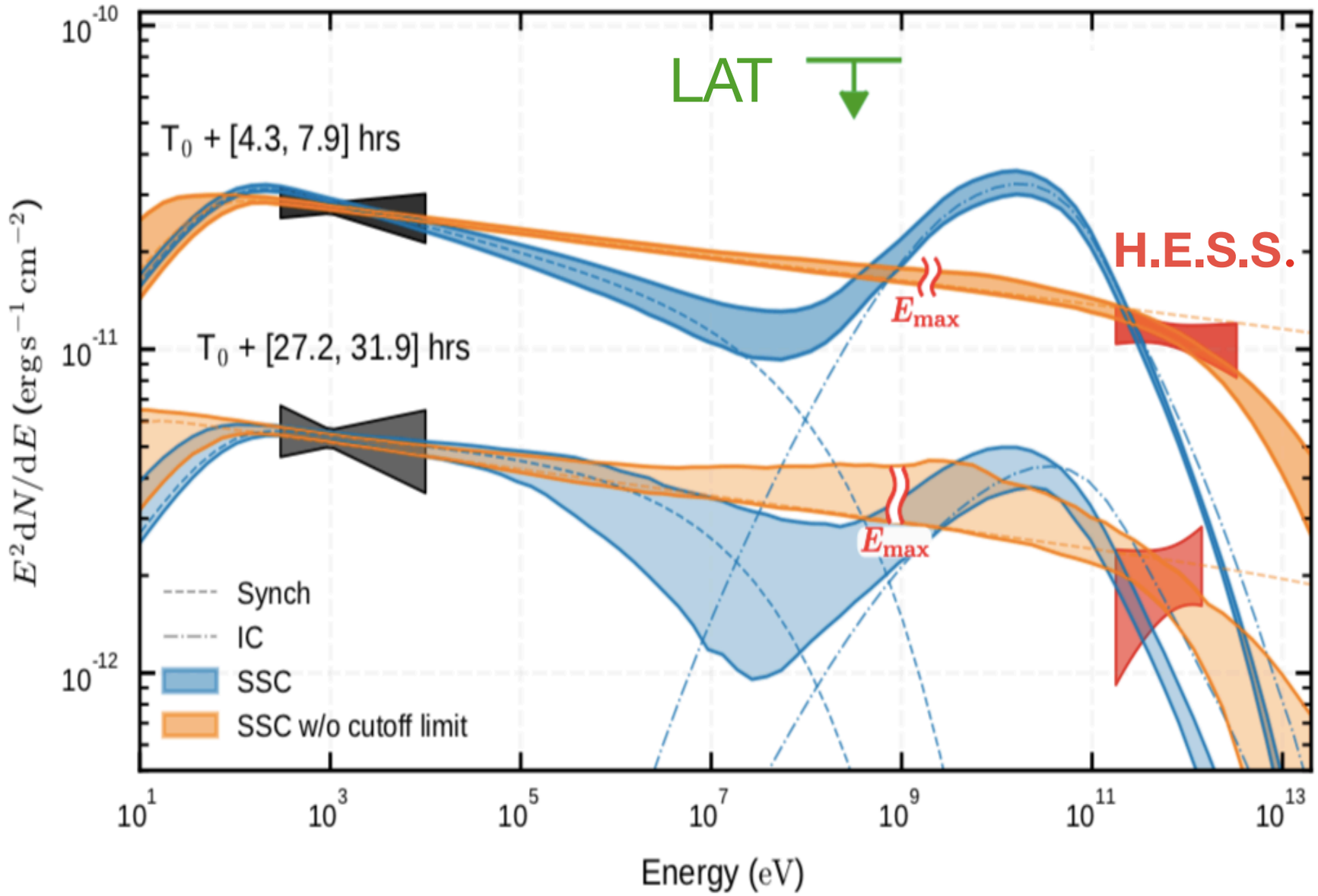
General properties

- Long GRB
- z = 0.079
- E_{prompt} = 2 x 10^{50}erg

HESS detection

- ~4 hours after the GRB
- in the energy range 0.2-3.3 TeV

H.E.S.S. Collab, 2019, Nature, 575, 464



TeV detections by IACTs

H.E.S.S. Detection of GRB 190829A

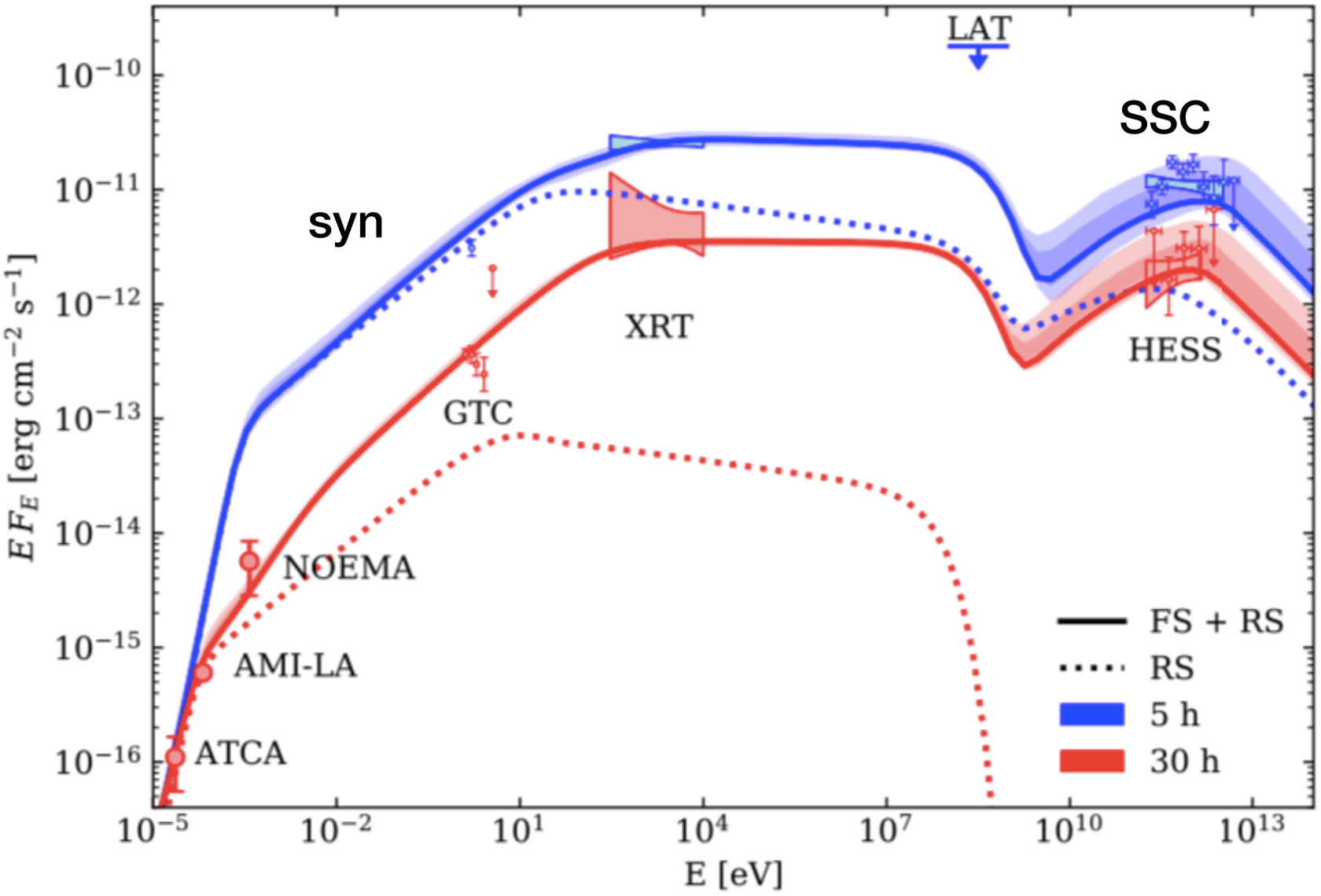
General properties

- Long GRB
- z = 0.079
- E_{prompt} = 2 x 10^{50}erg

HESS detection

- ~4 hours after the GRB
- in the energy range 0.2-3.3 TeV

Salafia et al. 2022, ApJ, 931L, 19



TeV detections by IACTs

MAGIC GRB 201216C

General properties

- Long GRB
- z = 1.1
- E_{prompt} = 5 x 10^{53} erg

MAGIC detection

- 57 seconds after the prompt
- Significance of detection ~6 sigma
- paper in preparation, almost ready for submission

Summary

WHAT HAVE WE LEARNED?

- Energy emitted at VHE can be similar to energy emitted at lower frequencies
- SSC is a viable explanation
- VHE emission can be produced by both energetics and under energetics GRBs
- VHE emission can last for days
- HE (LAT) observations are fundamental

OPEN QUESTIONS

- Origin of >100 GeV emission is still debated
- do short GRBs also have conditions to produce a detectable VHE flux?
- VHE emission during the prompt?

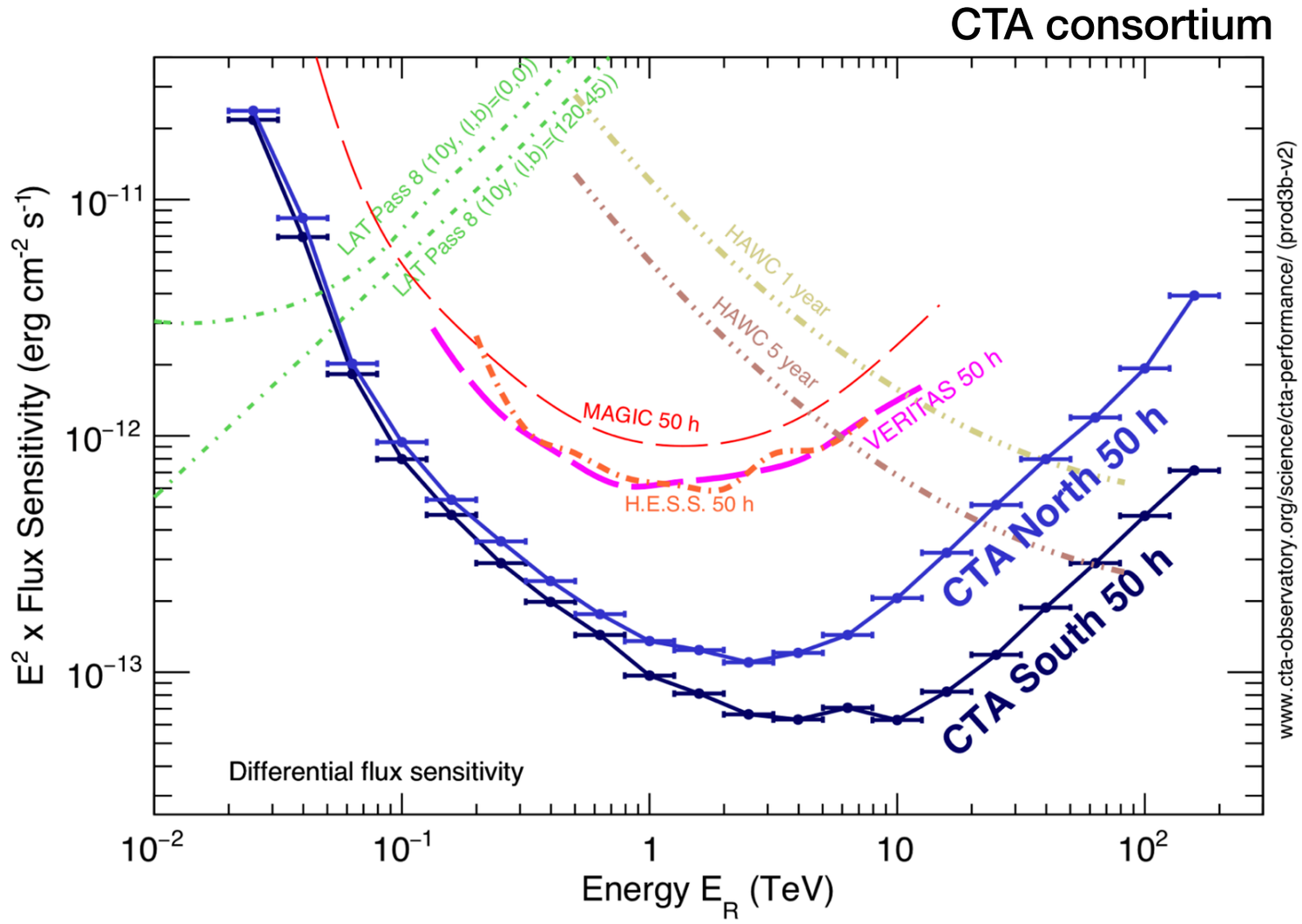
Future prospects

CTA - Cherenkov Telescope Array

LST: 20GeV - 3 TeV

MST: 80 GeV - 50 TeV

SST: 1 TeV - 300 TeV



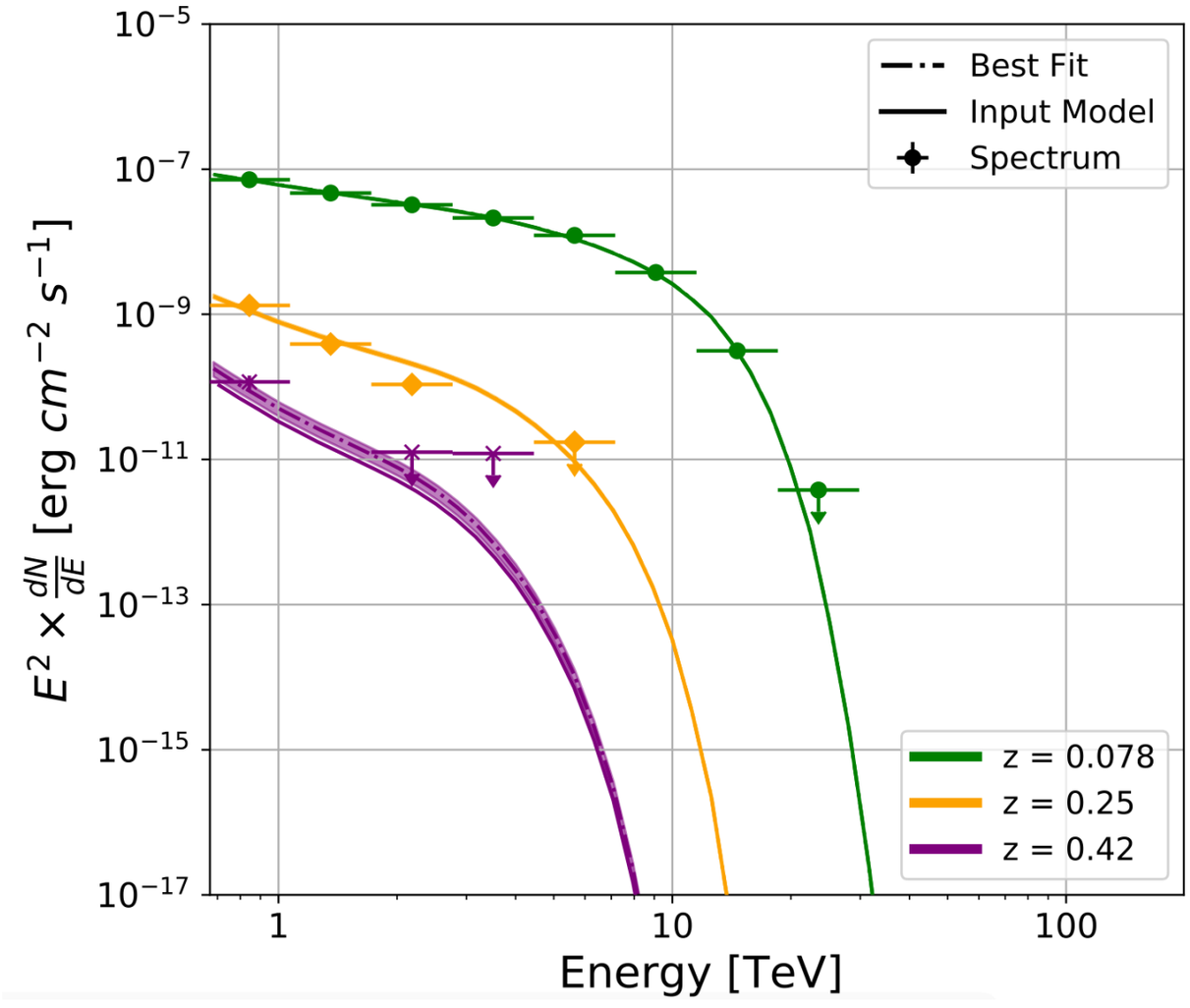
Consortium paper on prospects for CTA observations of GRB in preparation

Future prospects

The ASTRI-Mini Array

SIMULATIONS

- 190114C as a template
- moved at 3 different z:
  - z = 0.42 (original z)
  - z = 0.25
  - z = 0.078 (same as HESS GRB 190829A)



Vercellone et al., 2022
ASTRI Mini-Array core science at the Observatorio del Teide

GRB 221009A

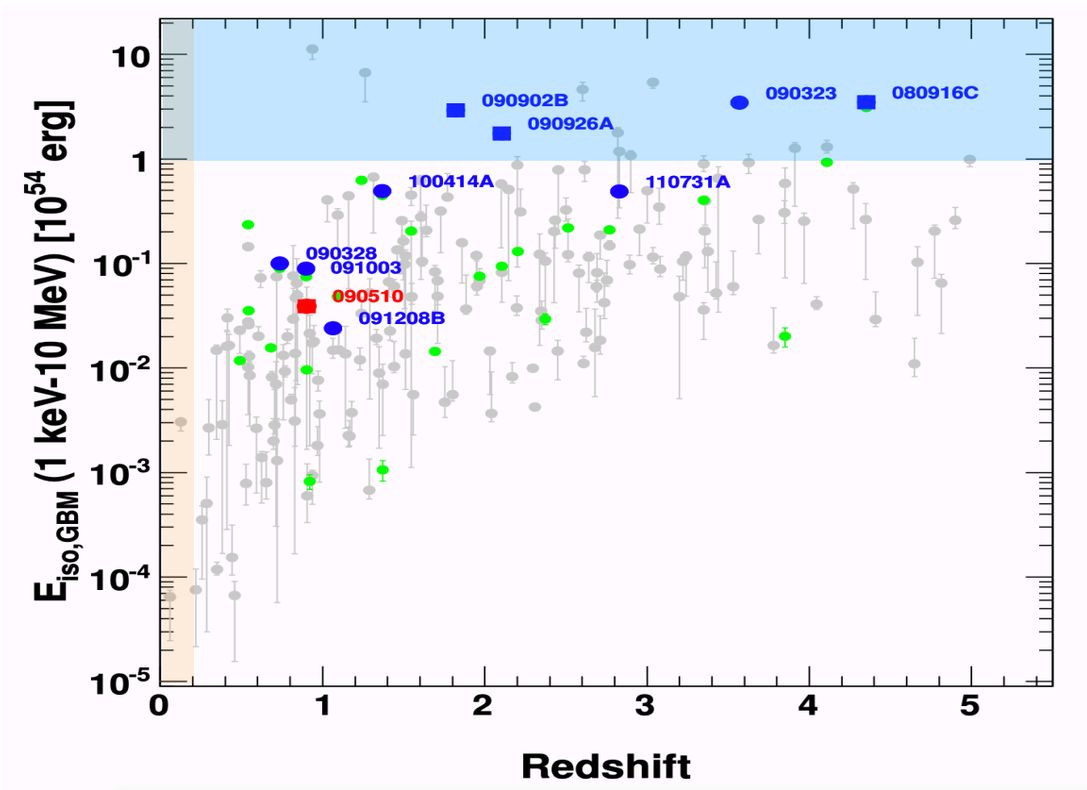
The brightest ever detected

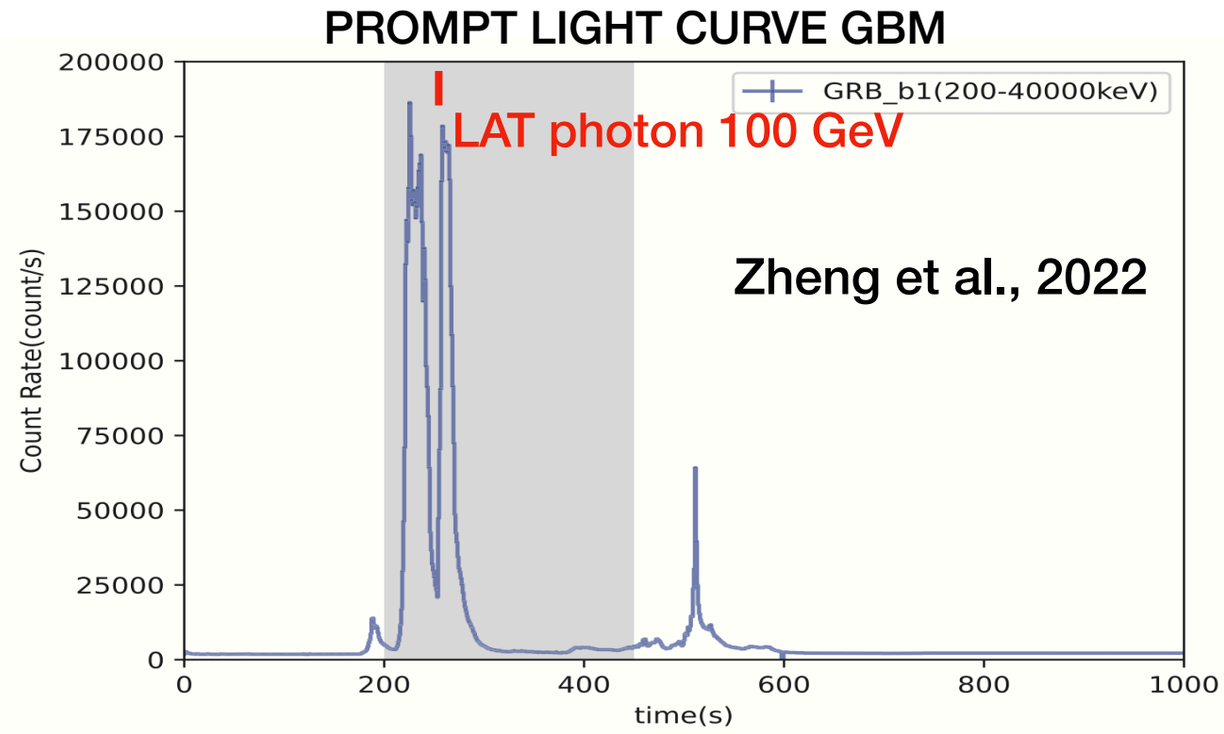
GRB 221009A

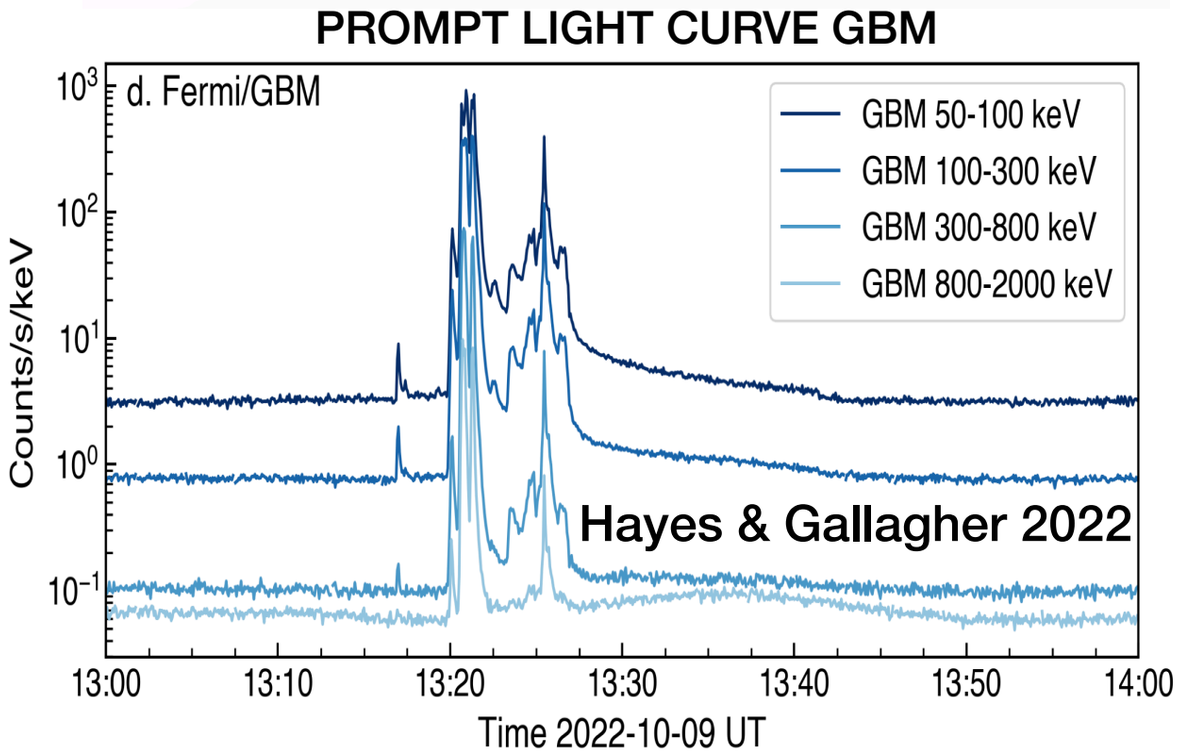
An intrinsically luminous GRB at z = 0.15

PROMPT

- GBM saturated
- LAT pile-up (200-800s, ph index = -1.87; one photon with 100 GeV at 240 s)
- E_{iso} ~ 10^{54} - 10^{55} erg
- L_{iso} ~ 10^{53} erg/s
- Duration ~ 600 s (long GRB)





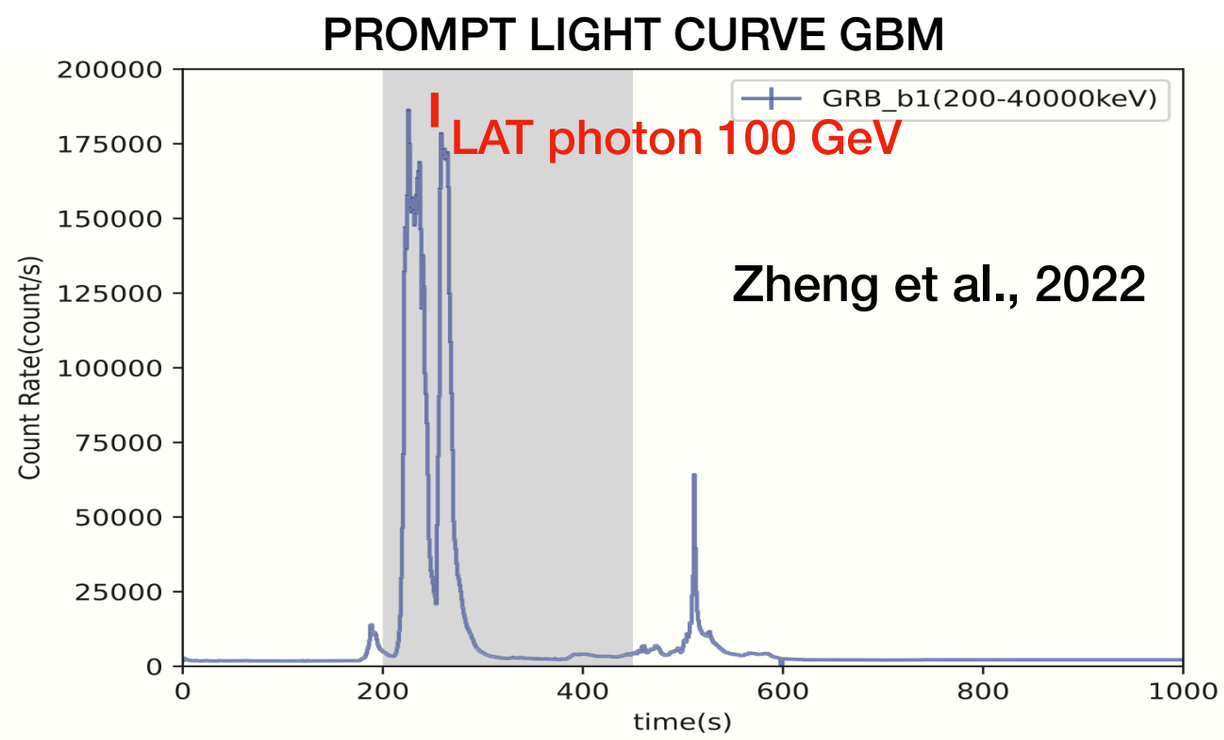


GRB 221009A

An intrinsically luminous GRB at z = 0.15

PROMPT

- GBM saturated
- LAT pile-up (200-800s, ph index = -1.87; one photon with 100 GeV at 240 s)
- E_{iso} ~ 10^{54} - 10^{55} erg
- L_{iso} ~ 10^{53} erg/s
- Duration ~ 500 s (long GRB)



AFTERGLOW

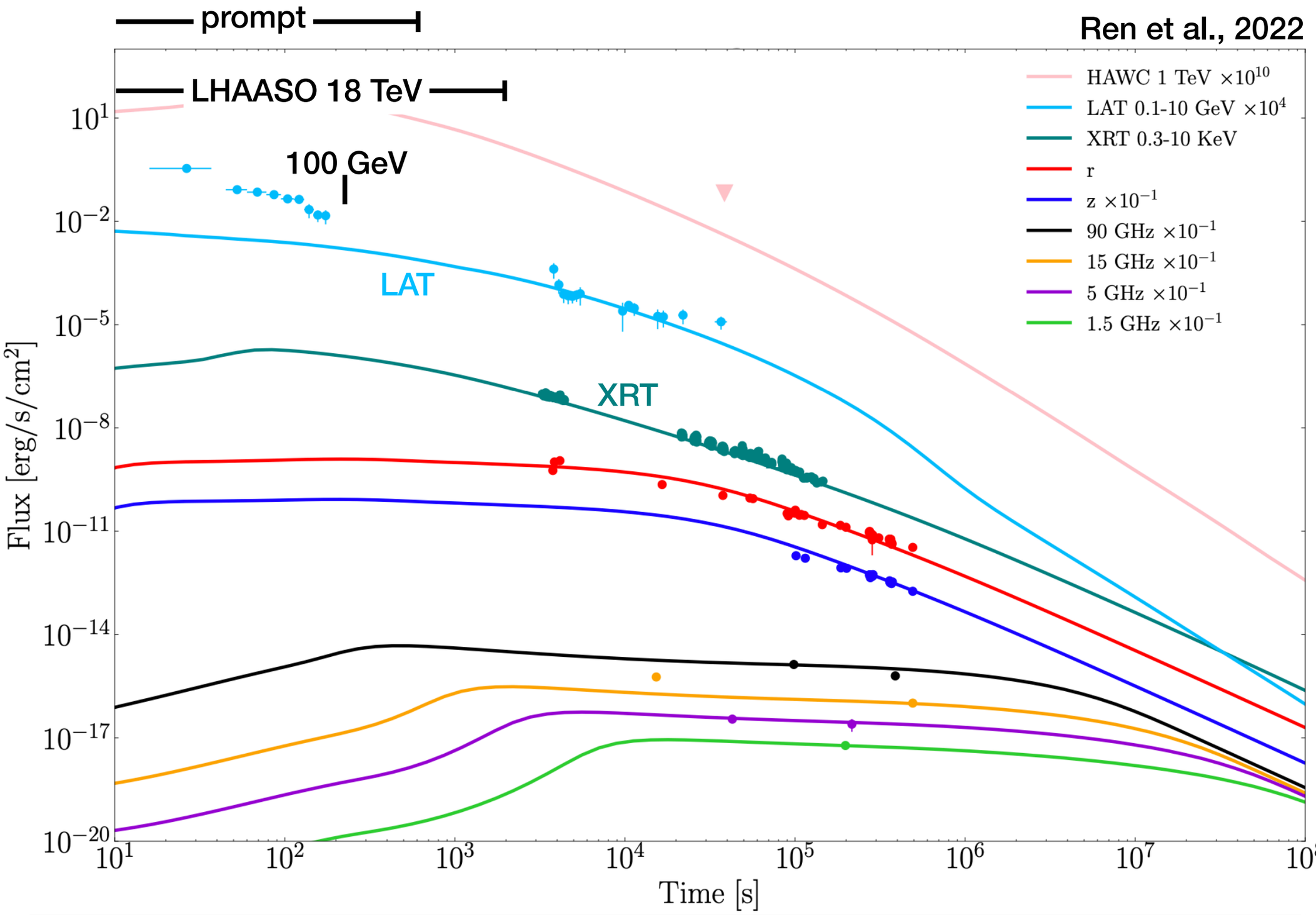
- XRT, optical, radio, LAT (~3600-6600s, photon index = -2.12)

OTHER OBSERVATIONS

- LHAASO in the first 2000 s >5000 photons above 0.5 TeV, maximum photon energy detected 18 TeV
- Carpet-2: 250 TeV-photon like air shower
- HAWC observations started 8 hours after T_0, no detection
- IceCUBE: zero track-like muon neutrinos from T_0-1 hour to T_0+2 hours
- KM3NeT: zero track-like muon neutrinos from T_0-50s to T_0+5000s

GRB 221009A

Afterglow emission

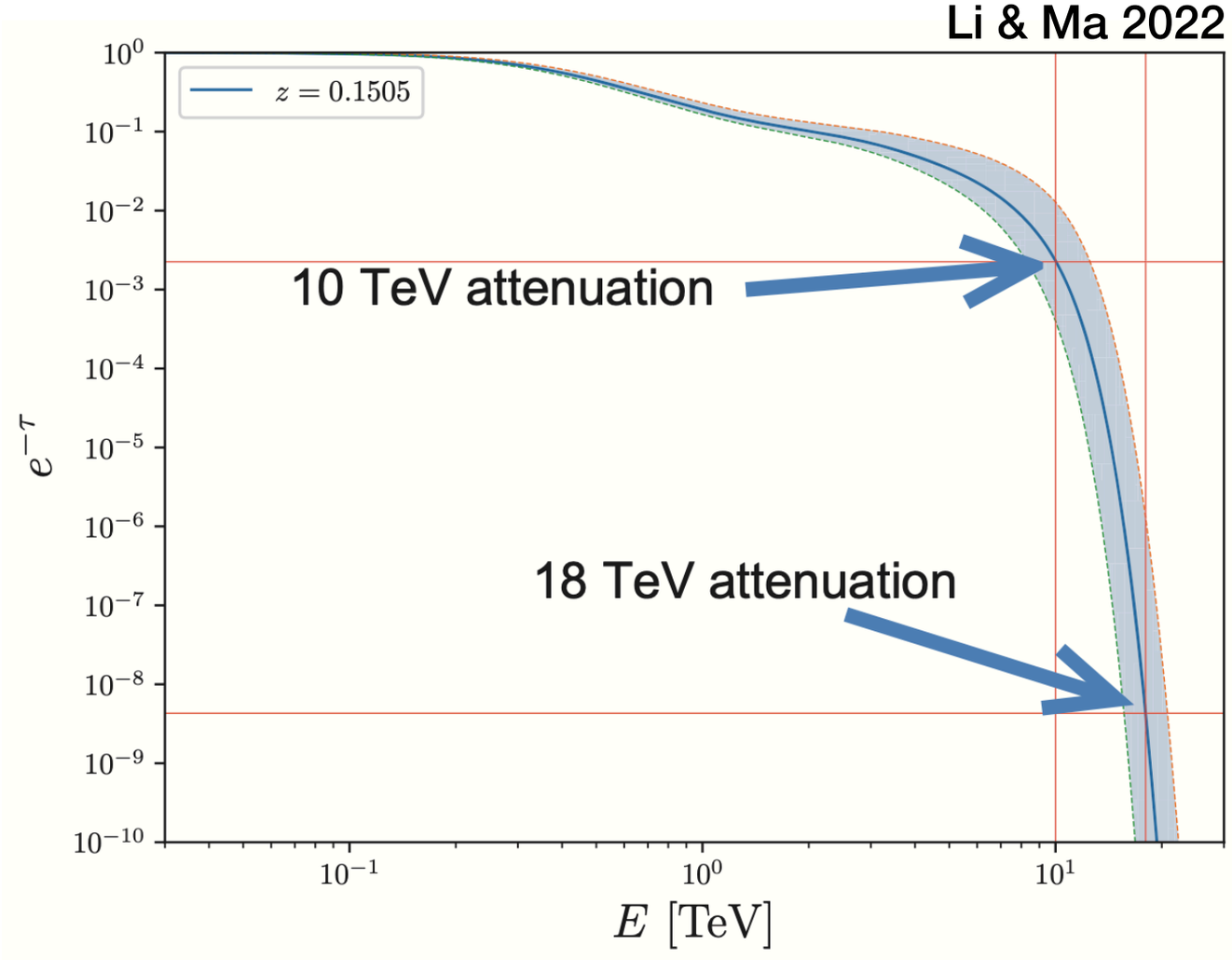


GRB 221009A

Why all this interest?

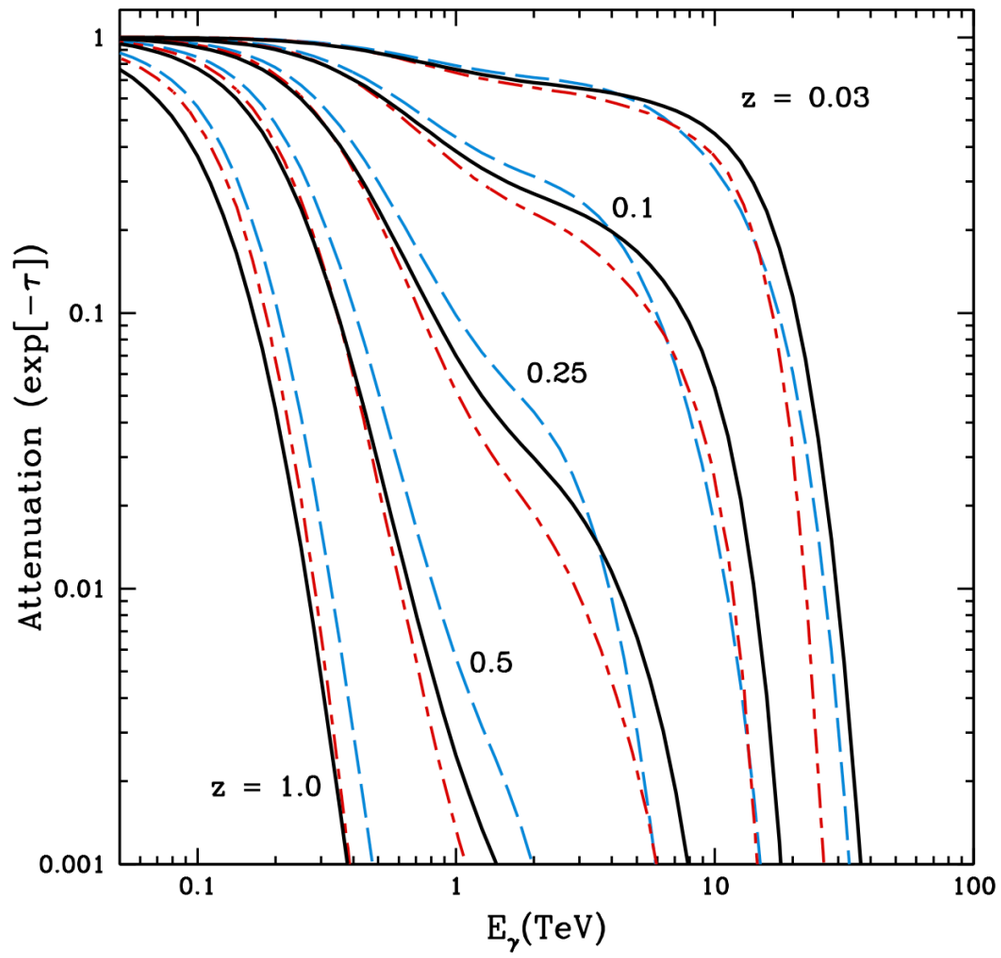
Consider EBL flux attenuation at 18 TeV and z=0.15:

Li & Ma 2022



EBL model from Dominguez et al. 2011

Gilmore et al., 2011



Dominguez EBL model

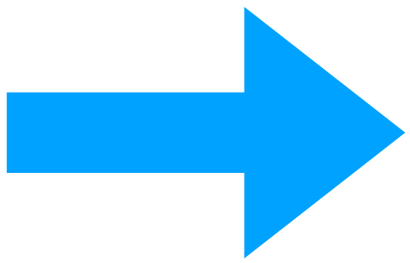
Gilmore EBL model

GRB 221009A

Overview on papers appeared on arXiv

Papers on the arXiv (26 in total)

- 9 discuss ALP (axion-like particles)
- 6 LIV ($\gamma\gamma$-e^+e^- threshold anomaly)
- 3 UHECR
- 3 heavy sterile neutrinos
- 1 Galactic lensing
- 1 ionospheric disturbance
- 2 GRB physics
  - 1 IceCUBE limit to constrain prompt emission models
  - 1 afterglow SSC to explain 18 TeV



most papers on astroparticle,
LIV, IGMF,…

GRB 221009A

Is the 18 TeV photon really problematic?

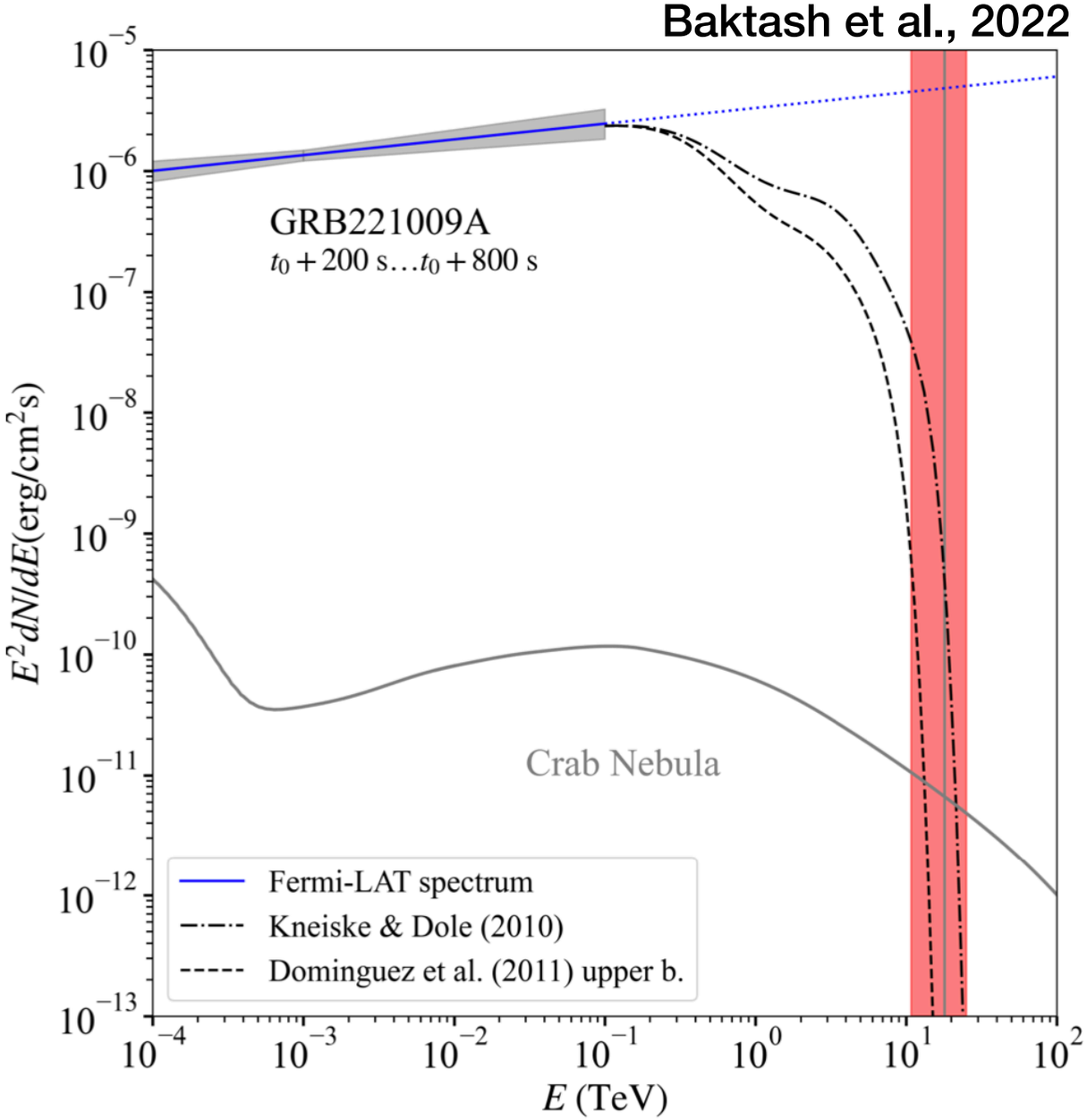
The answer depends on:

- Intrinsic source spectrum
- EBL model
- LHAASO sensitivity
- LHAASO energy resolution
- Time of detection

EBL Model	τ_{18}	τ_{10}	$N_{\gamma,0.5}$	$N_{\gamma,18}$
Fr2008	18.2	6.7	4900	6×10^{-4}
SL2021	19.1	6.9	5100	3×10^{-4}
K&D2010	9.2	4.5	6800	5
Fi2010	9.9	6.0	4000	3
Do2011	19.2	6.1	4500	2×10^{-4}
Do2011+	27.1	7.8	3900	9×10^{-8}
Do2011-	13.5	4.4	5800	7×10^{-2}
Gi2012	13.3	5.4	4500	9×10^{-2}
Gi2012f	13.8	5.6	5600	5×10^{-2}

Baktash et al., 2022

Baktash et al., 2022



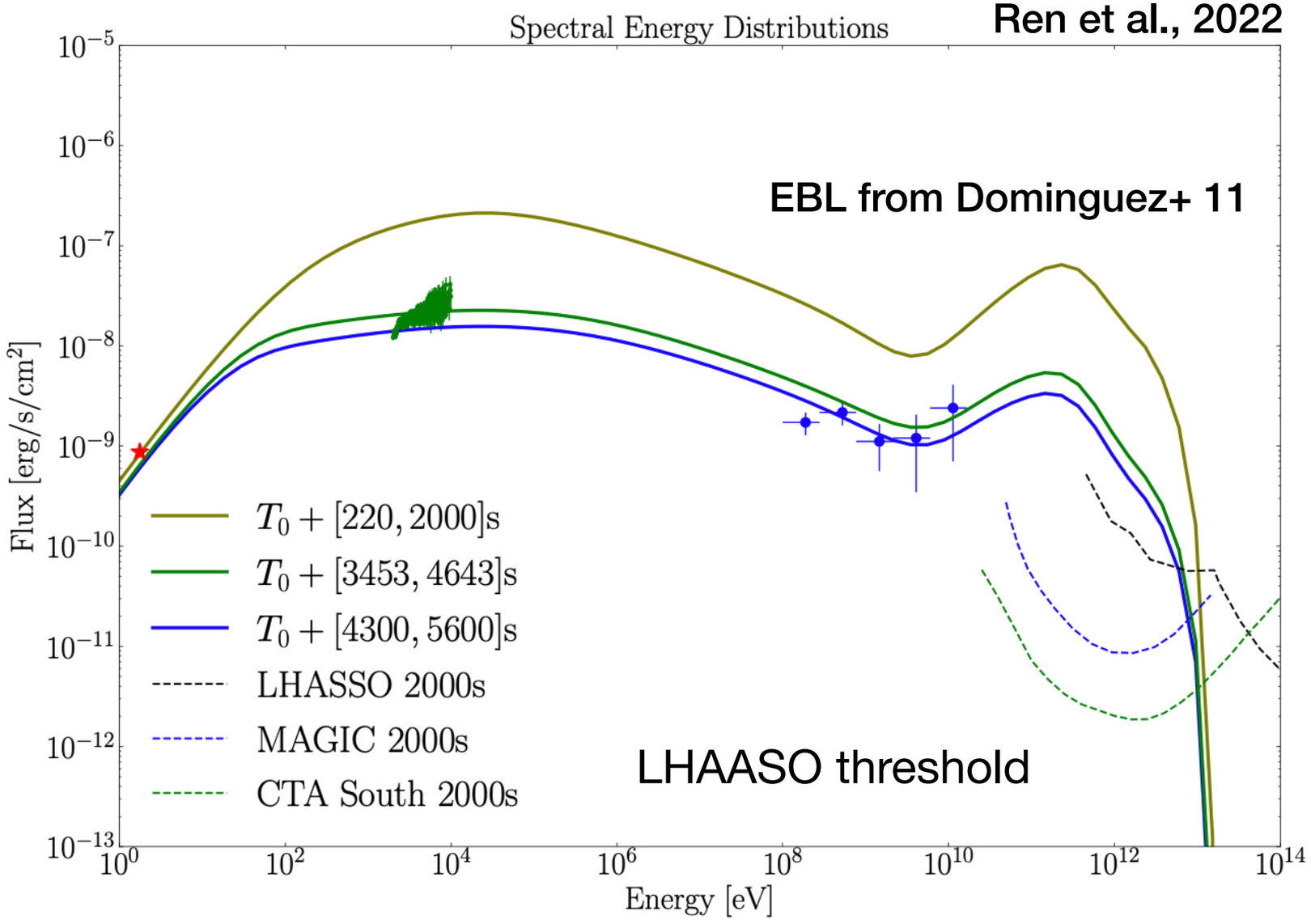
GRB 221009A

Is the 18 TeV photon really problematic?

The answer depends on:

- Intrinsic source spectrum
- EBL model
- LHAASO sensitivity
- LHAASO energy resolution
- Time of detection

Ren et al., 2022



THANK YOU FOR YOUR ATTENTION

Lara Nava

INAF

Osservatorio Astronomico di Brera