VHE emission in GRBs: What We Know So Far

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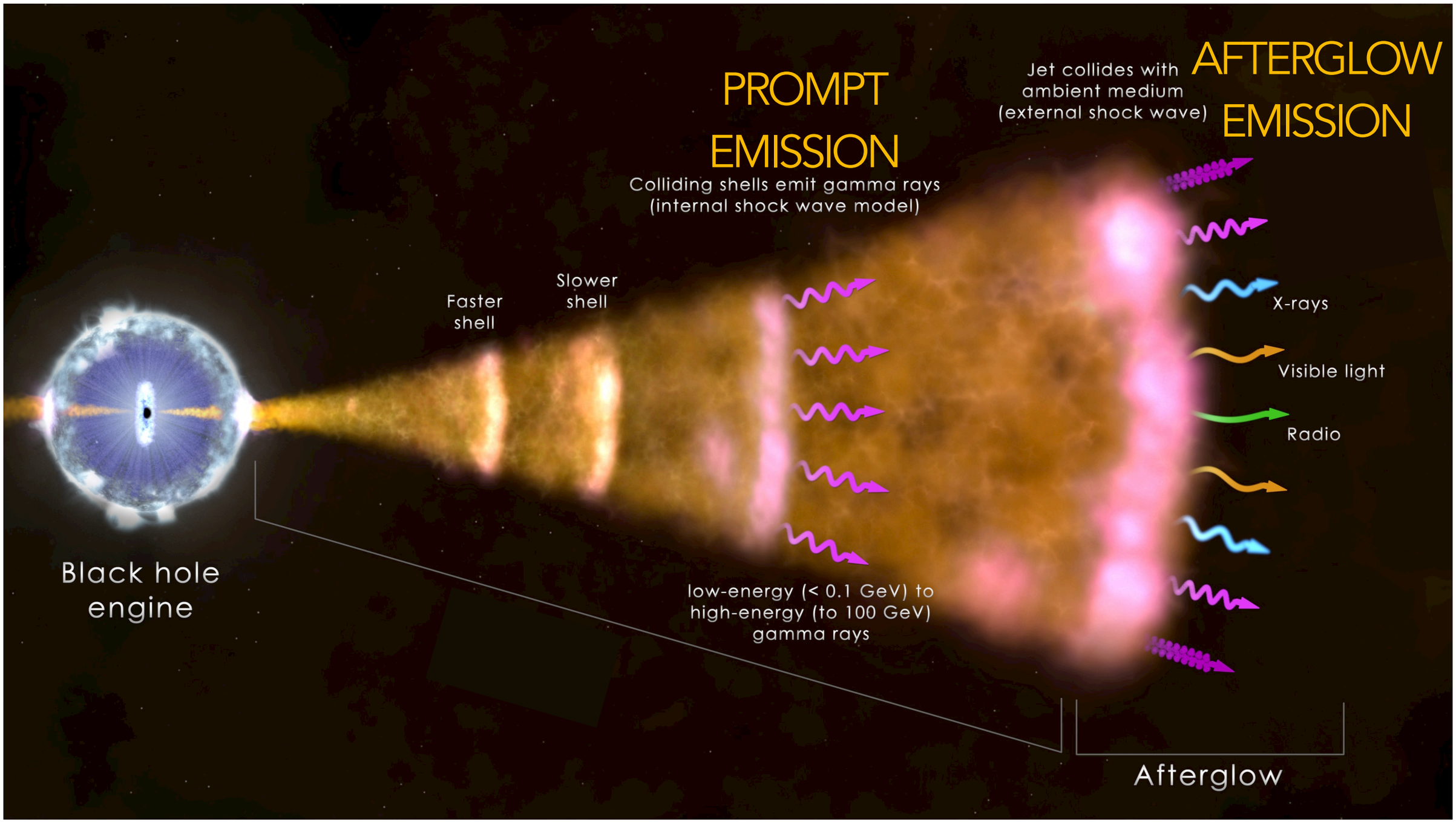
Gamma-Ray Bursts (GRB)

The general picture



Prompt emission

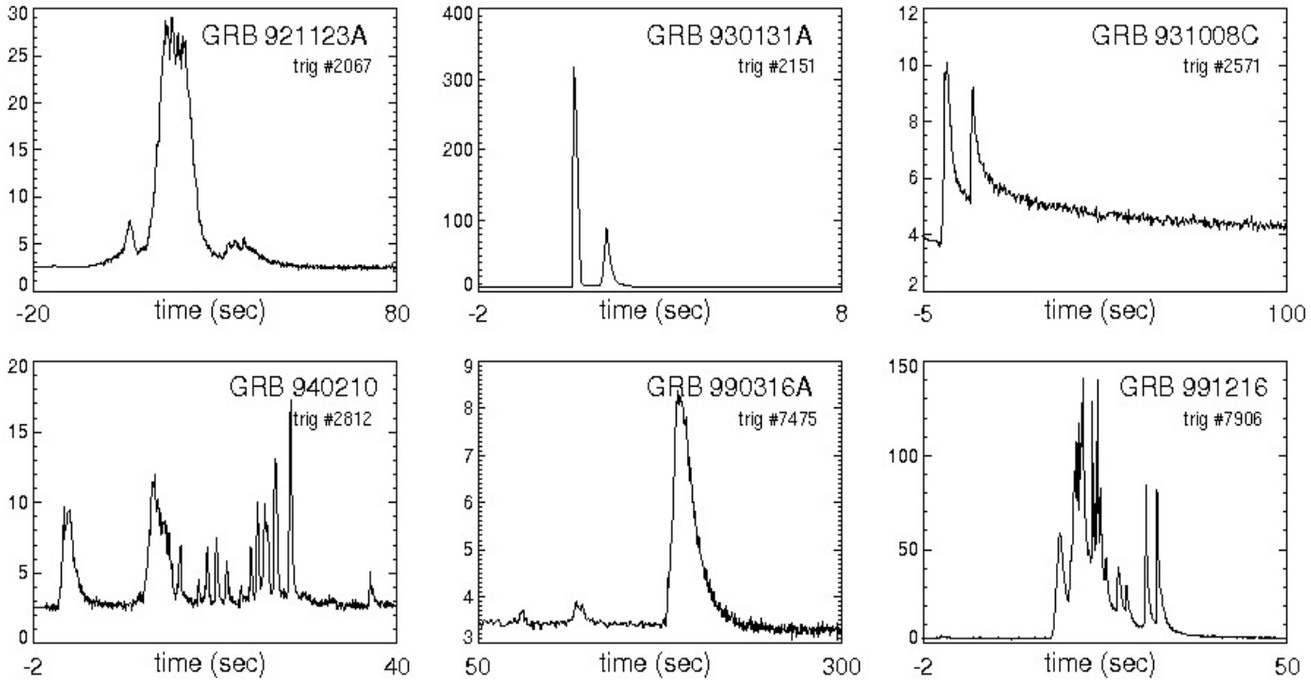
OBSERVATIONS

- keV - MeV
- Large variability (0.01 s)
- Short duration (0.1-1000 s)
- Non-thermal spectra

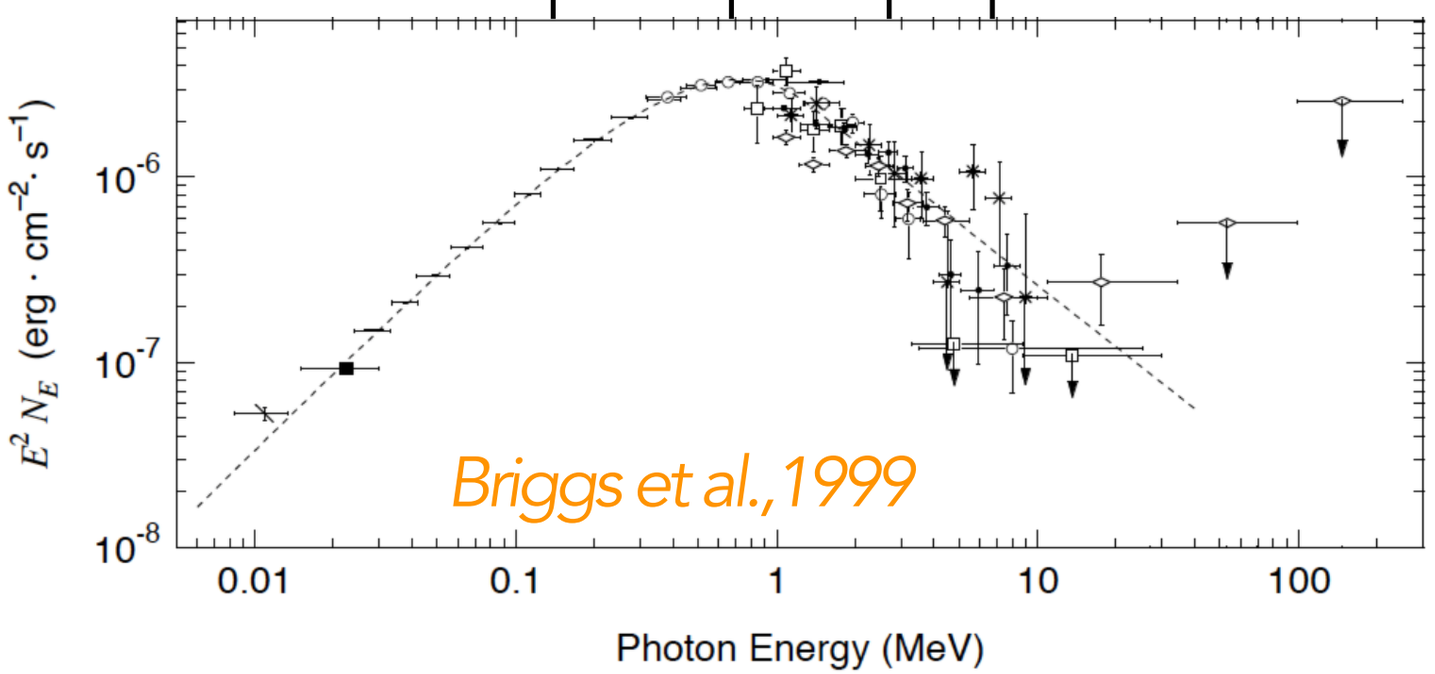
OPEN ISSUES

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

Examples of prompt light-curves



Example of prompt spectrum



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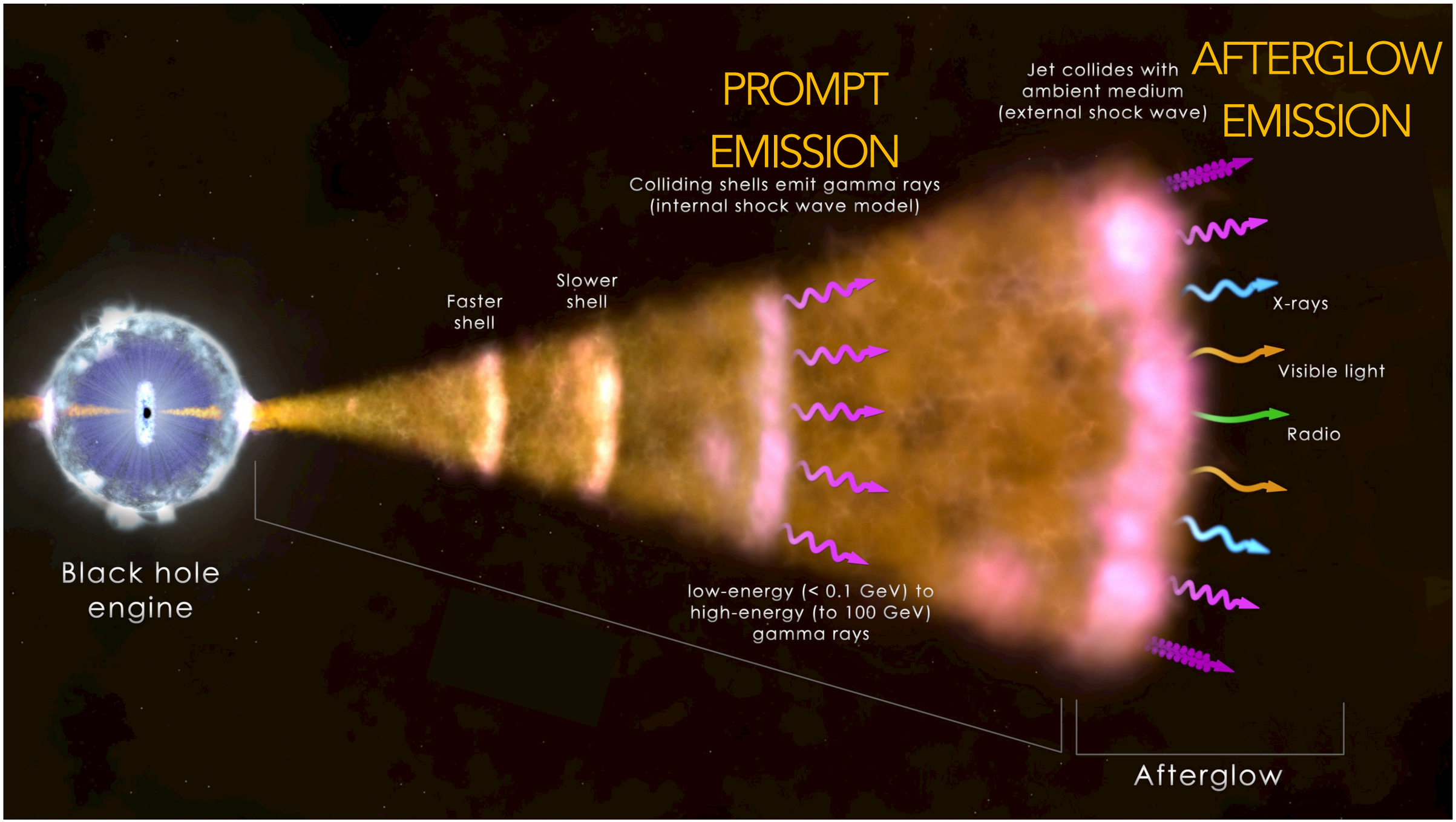


Afterglow emission

OBSERVATIONS

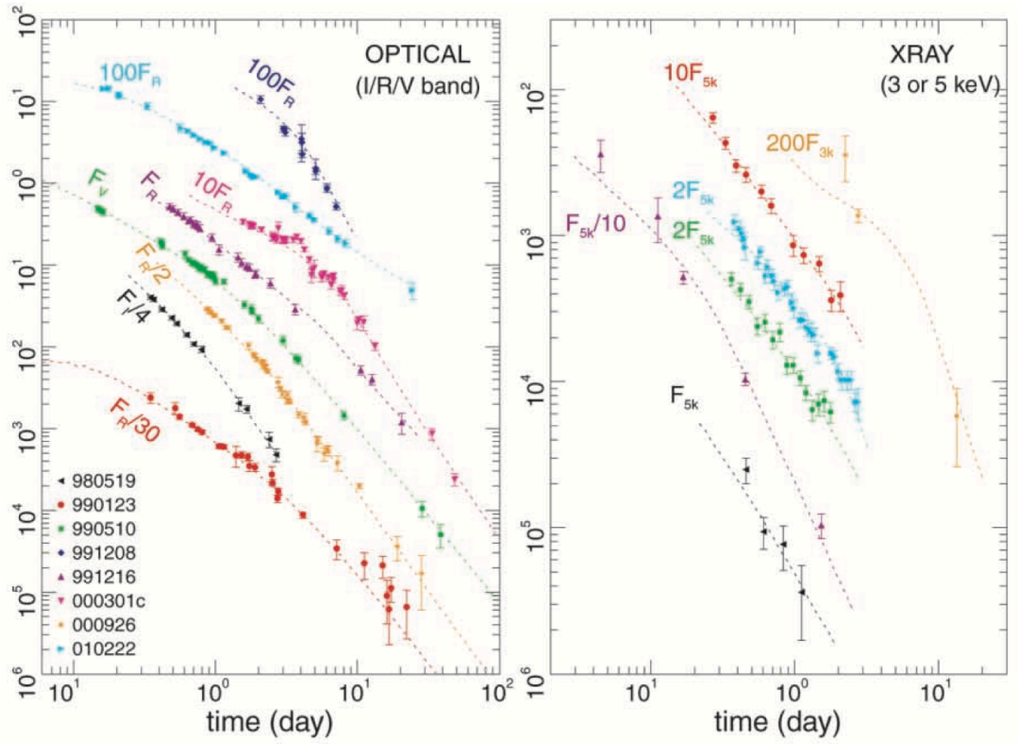
- Longer duration
- smooth light-curves (PL decay)
- Soft X-ray to radio
- GeV

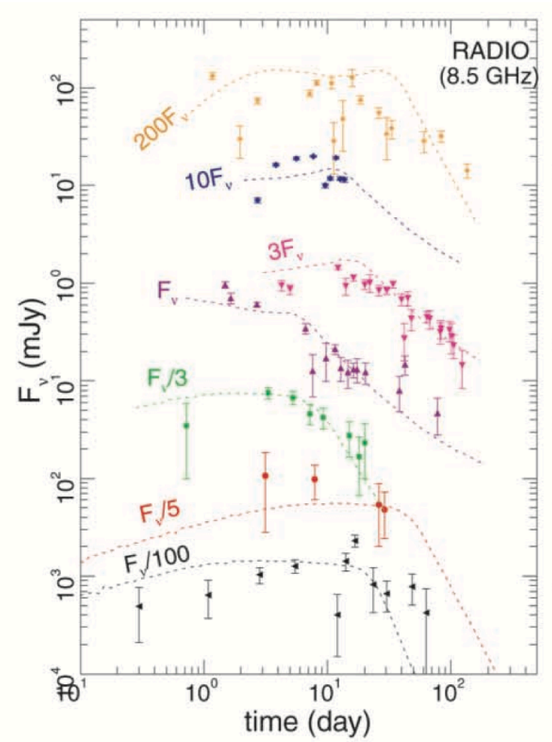
INTERPRETATION

- synchrotron, mostly 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)

RELEVANCE OF VHE OBSERVATIONS

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

STATUS

- GRBs have eluded Cherenkov telescopes for many years
- Until 2019 unclear if GRBs are VHE emitters
- Not robust predictions from theory
- Since 2019: five detections

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 —> I will focus on these GRBs

TeV detections by IACTs

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

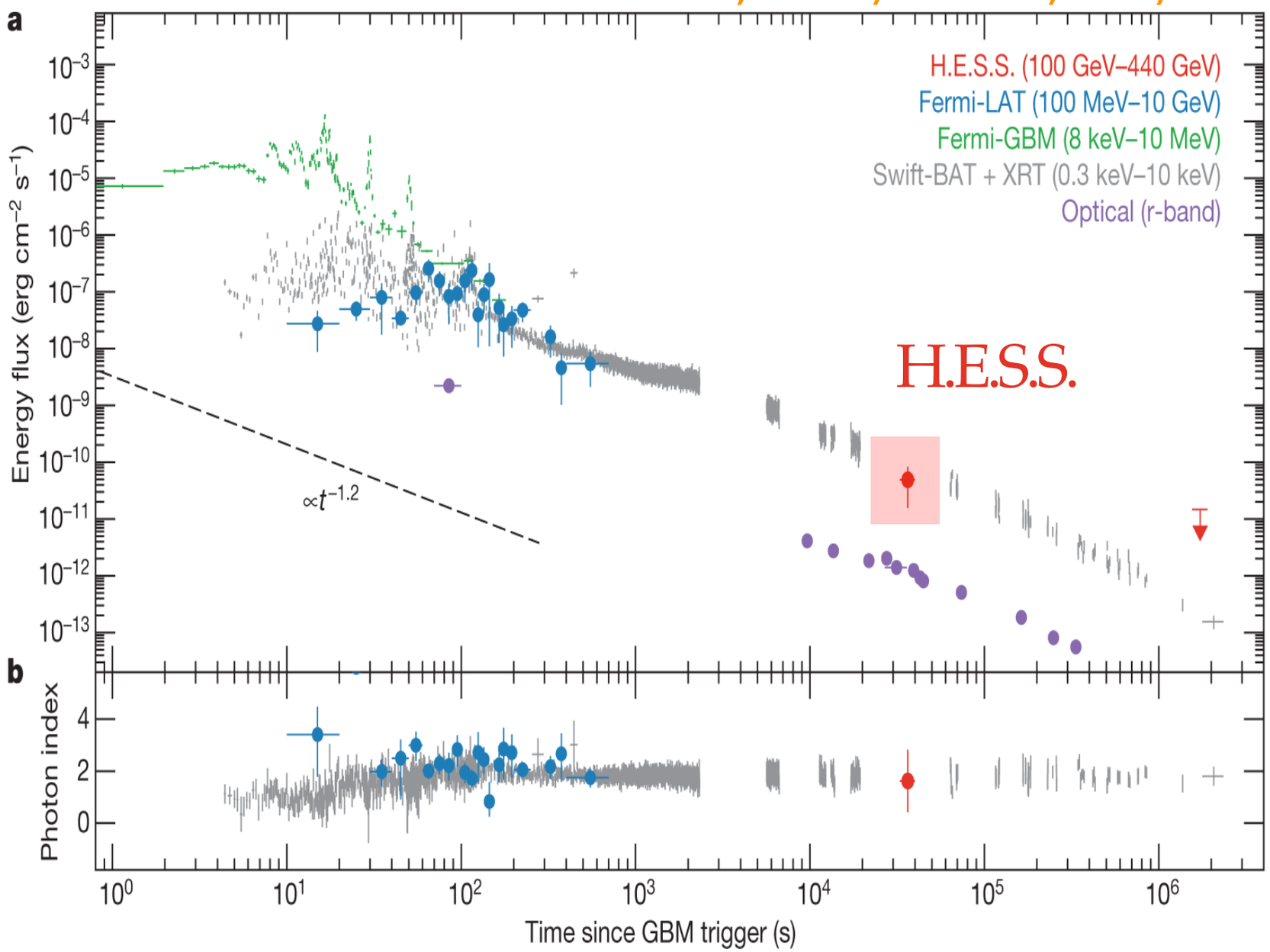
General properties

- Long GRB
- z = 0.65
- $E_{prompt} = 6 \times 10^{53}$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



See also modeling by Wang X.Y., Liu R.Y., Zhang H.M., 2019

TeV detections by IACTs

MAGIC Detection of GRB 190114C

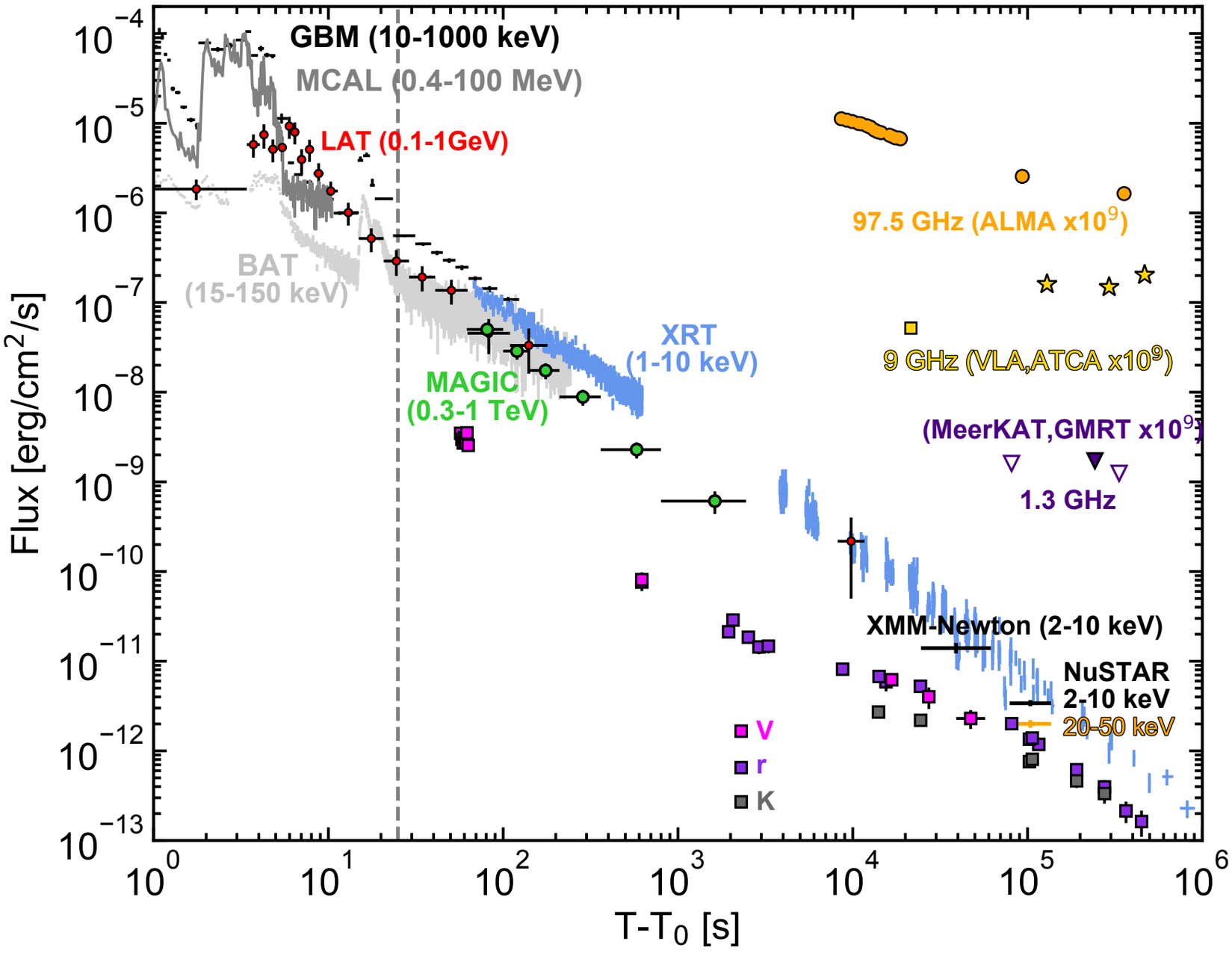
General properties

- 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



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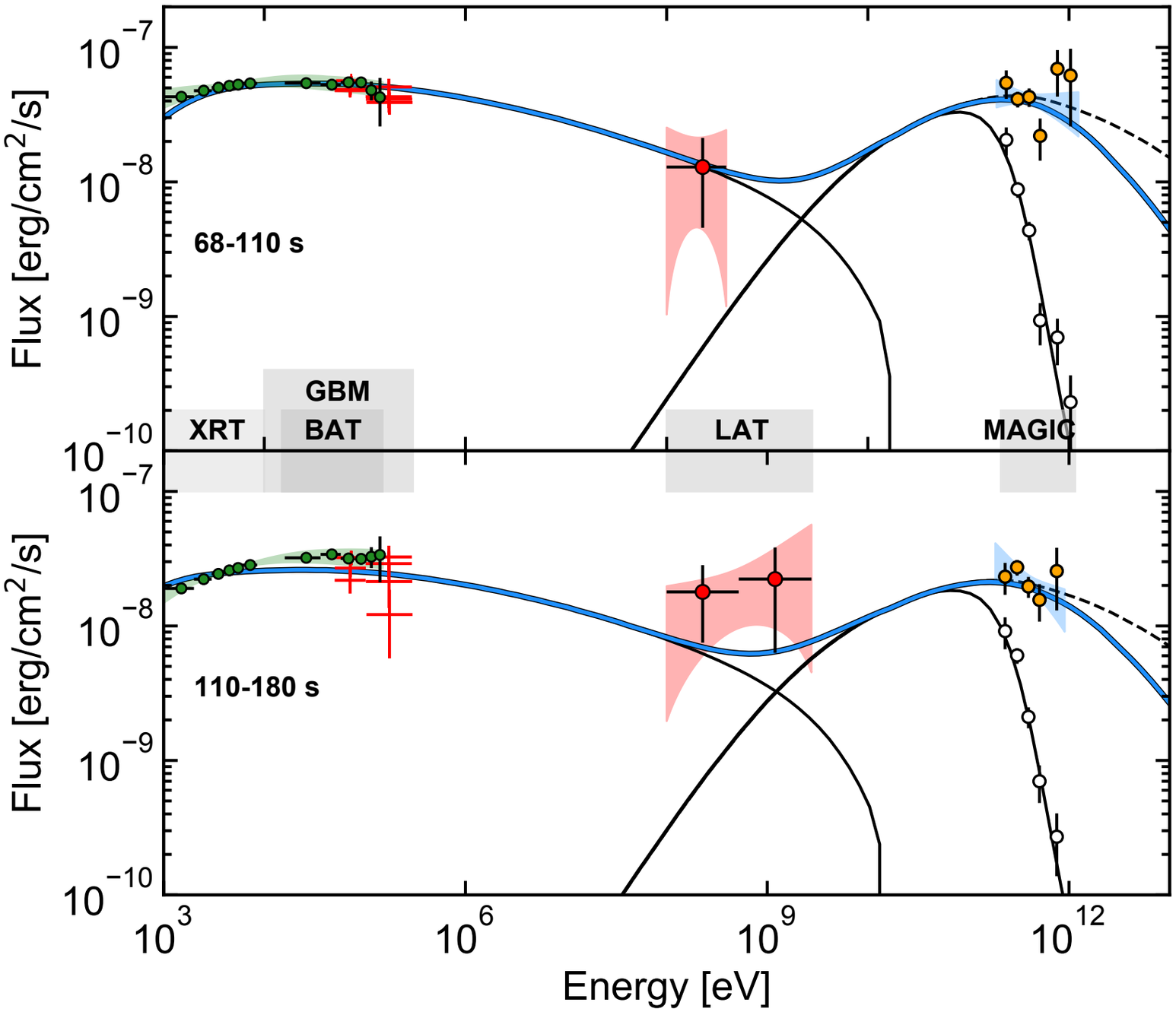

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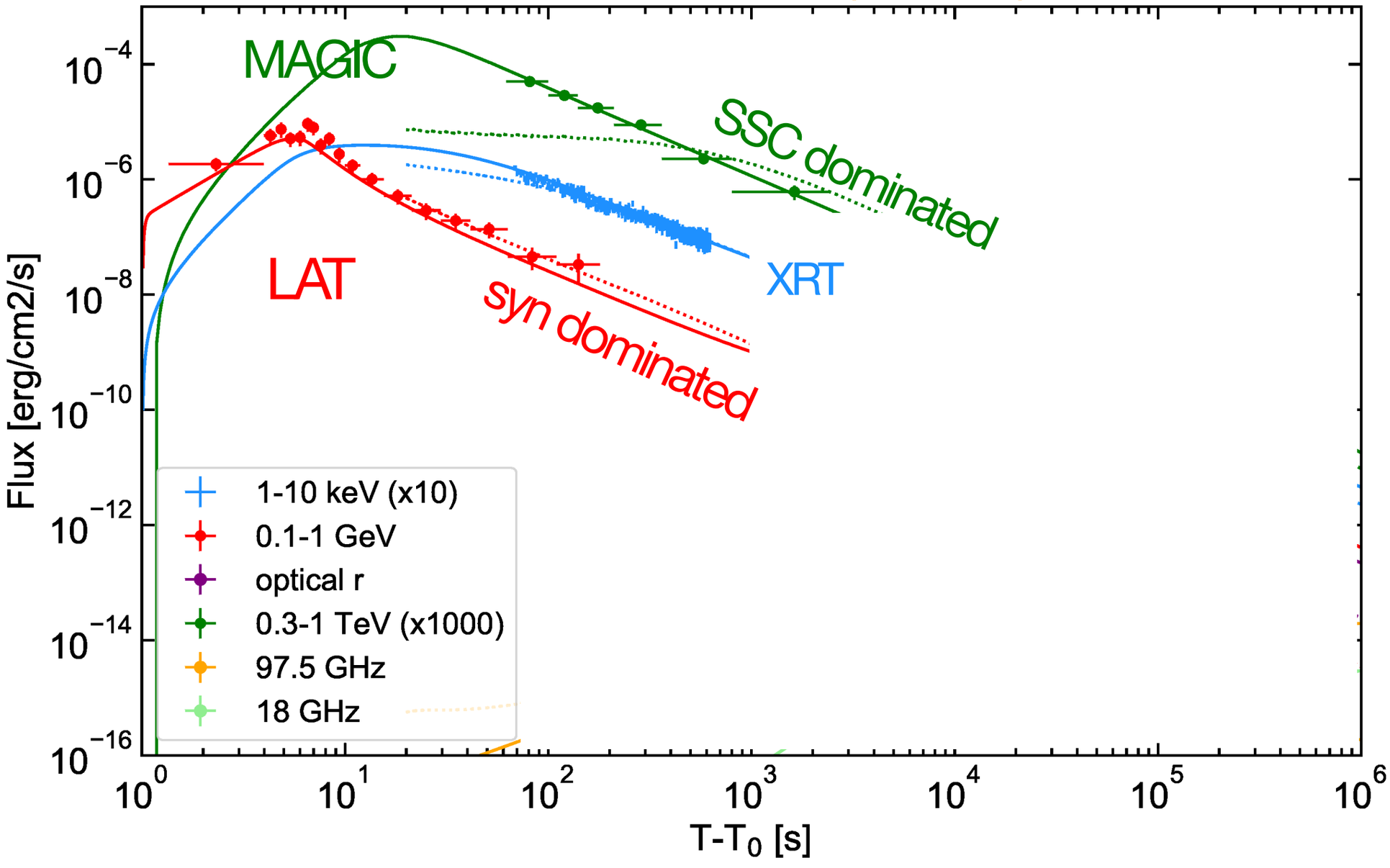

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Wang X.Y., et al., 2019
Asano K. et al., 2020
Josh et al., 2021
Derisive & Piran 2021

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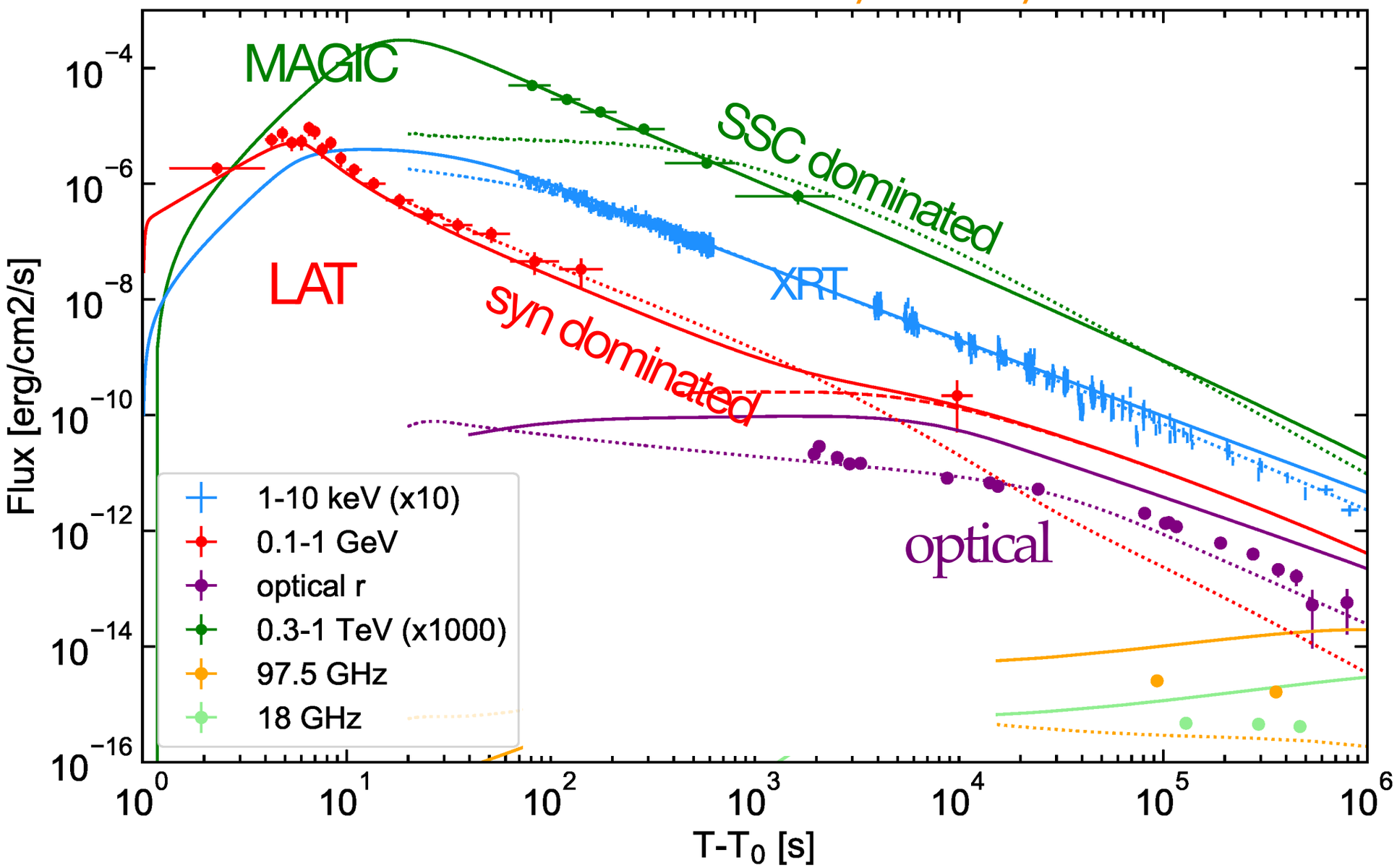

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TeV detections by IACTs

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

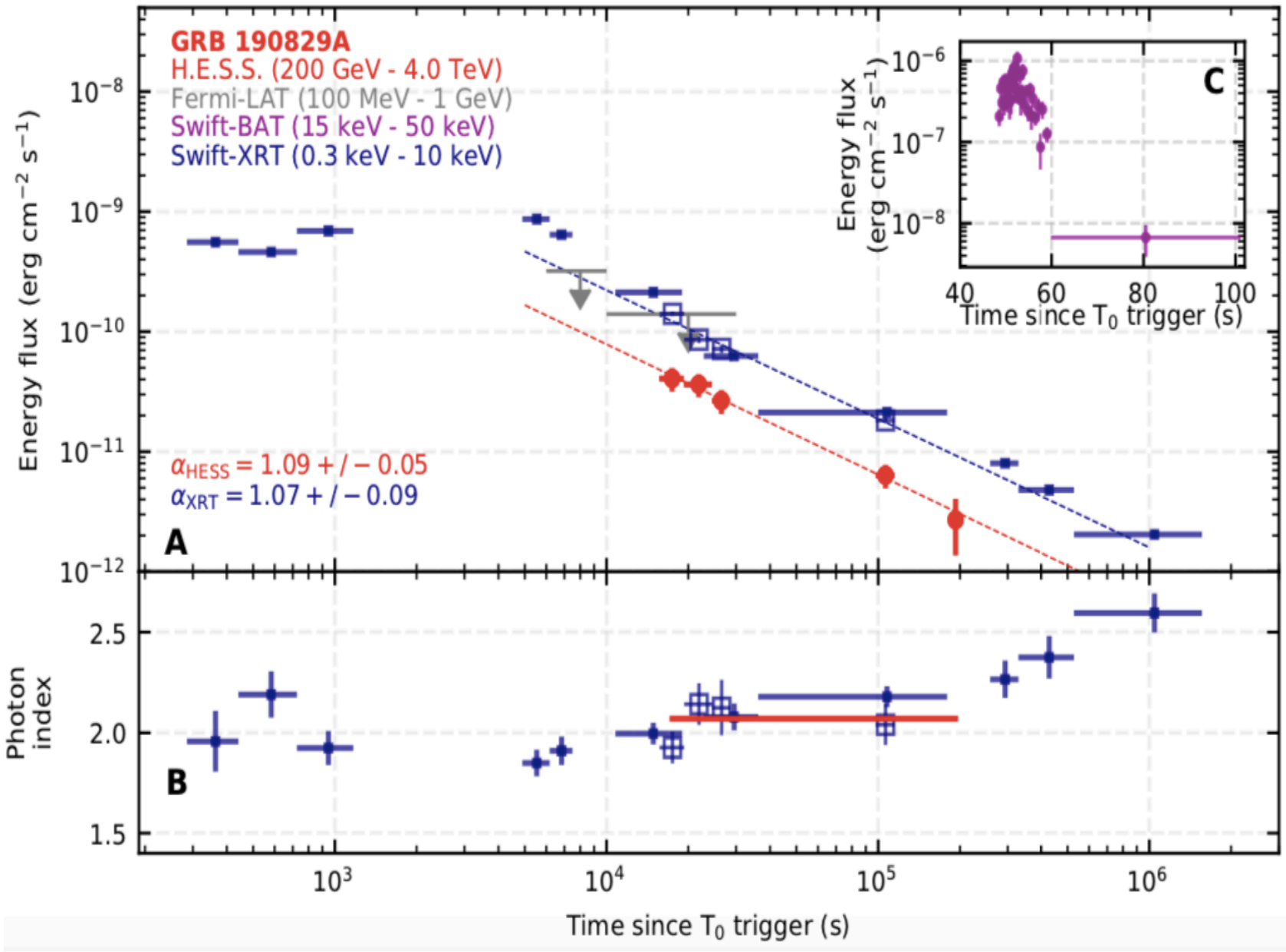
H.E.S.S. Collab, 2019, Nature, 575, 464

General properties

- Long GRB
- z = 0.079
- $E_{prompt} = 2 \times 10^{50}$erg

HESS detection

- ~4 hours to 3 days
- in the energy range 0.2 - 3.3 TeV



TeV detections by IACTs

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

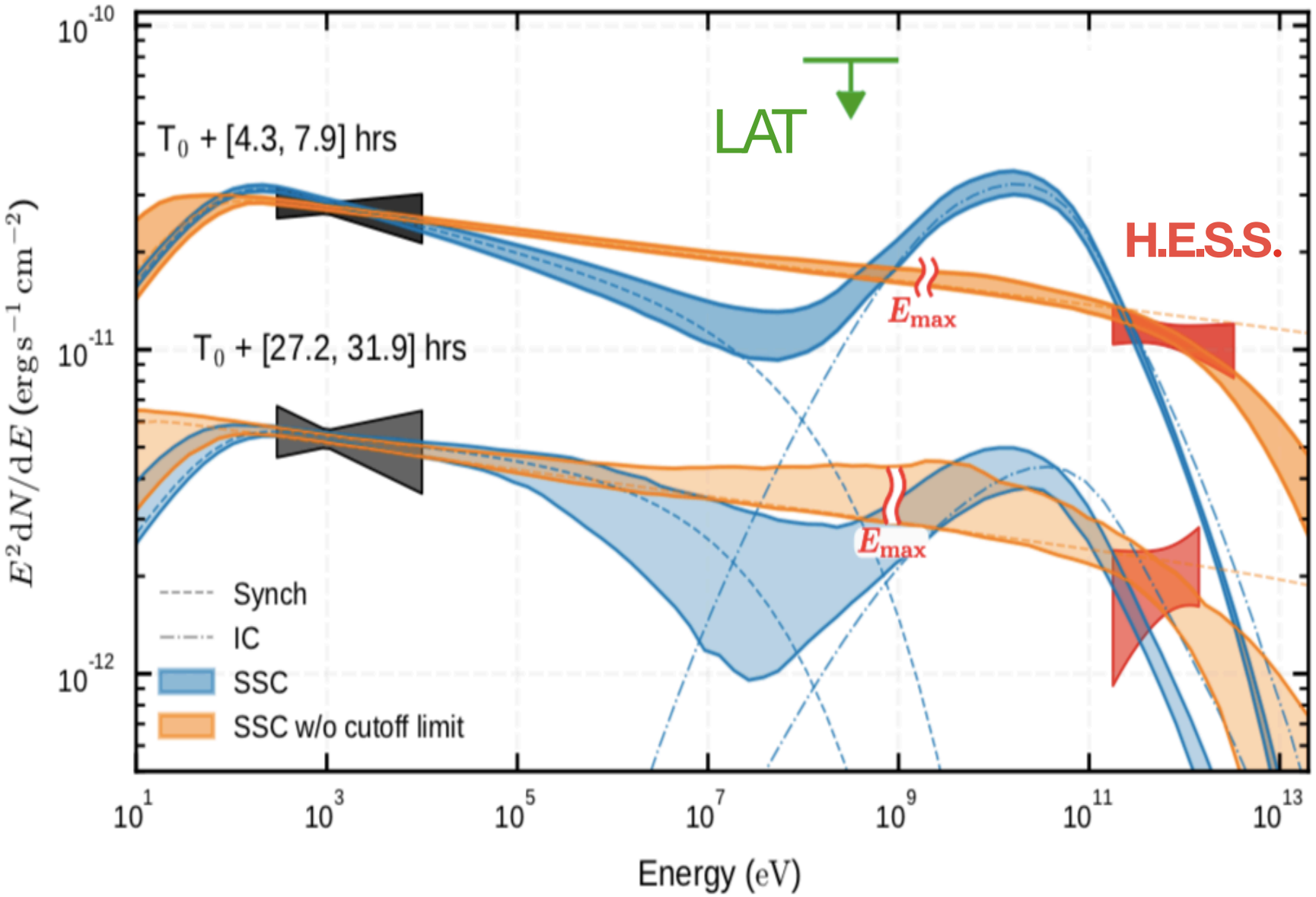
General properties

- Long GRB
- z = 0.079
- $E_{prompt} = 2 \times 10^{50}$erg

HESS detection

- ~4 hours to 3 days
- in the energy range 0.2 - 3.3 TeV

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



See also Khangulyan D., Taylor A. M., Aharonian F., 2023

TeV detections by IACTs

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

General properties

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- z = 0.079
- $E_{prompt} = 2 \times 10^{50}$erg

HESS detection

- ~4 hours to 3 days
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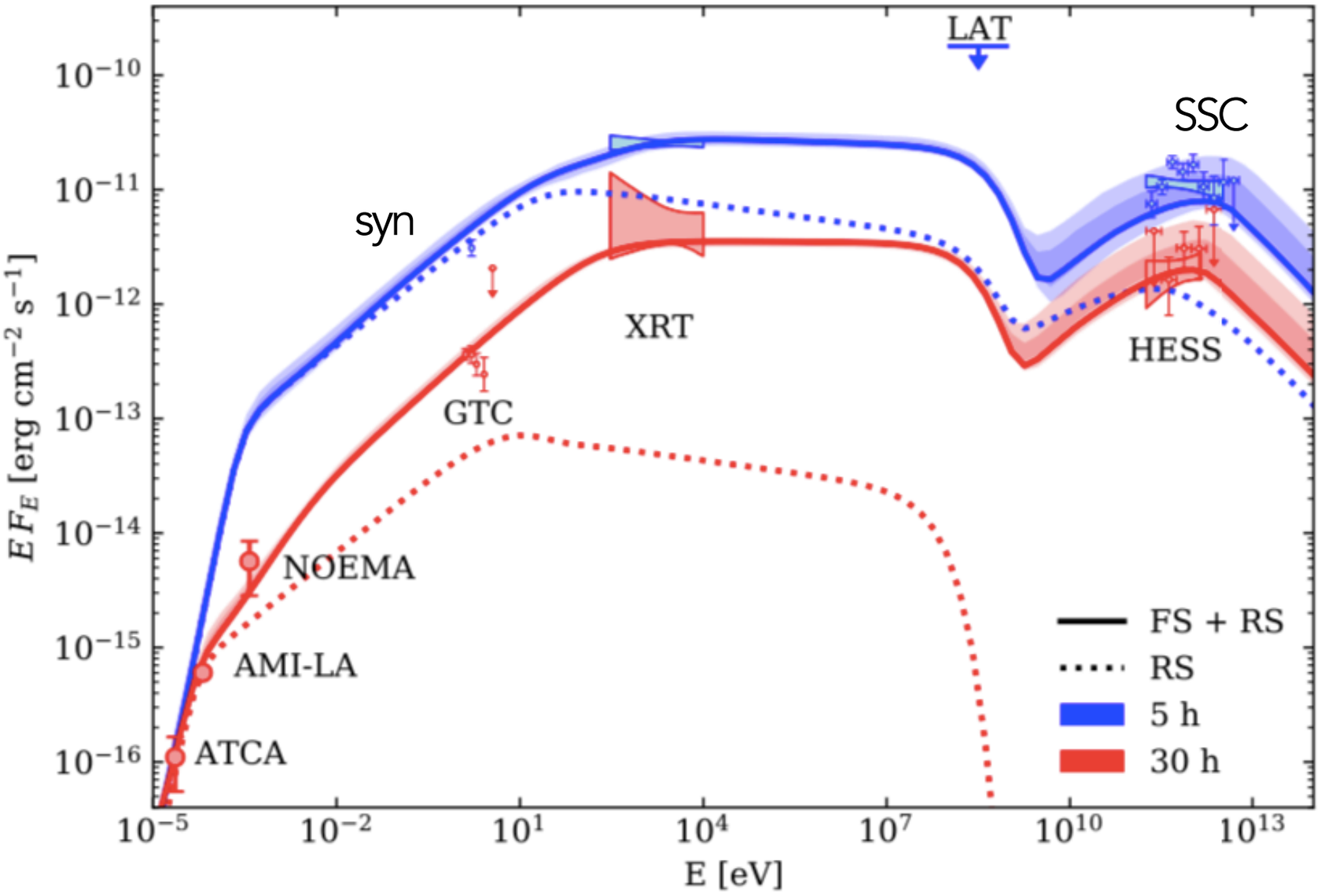
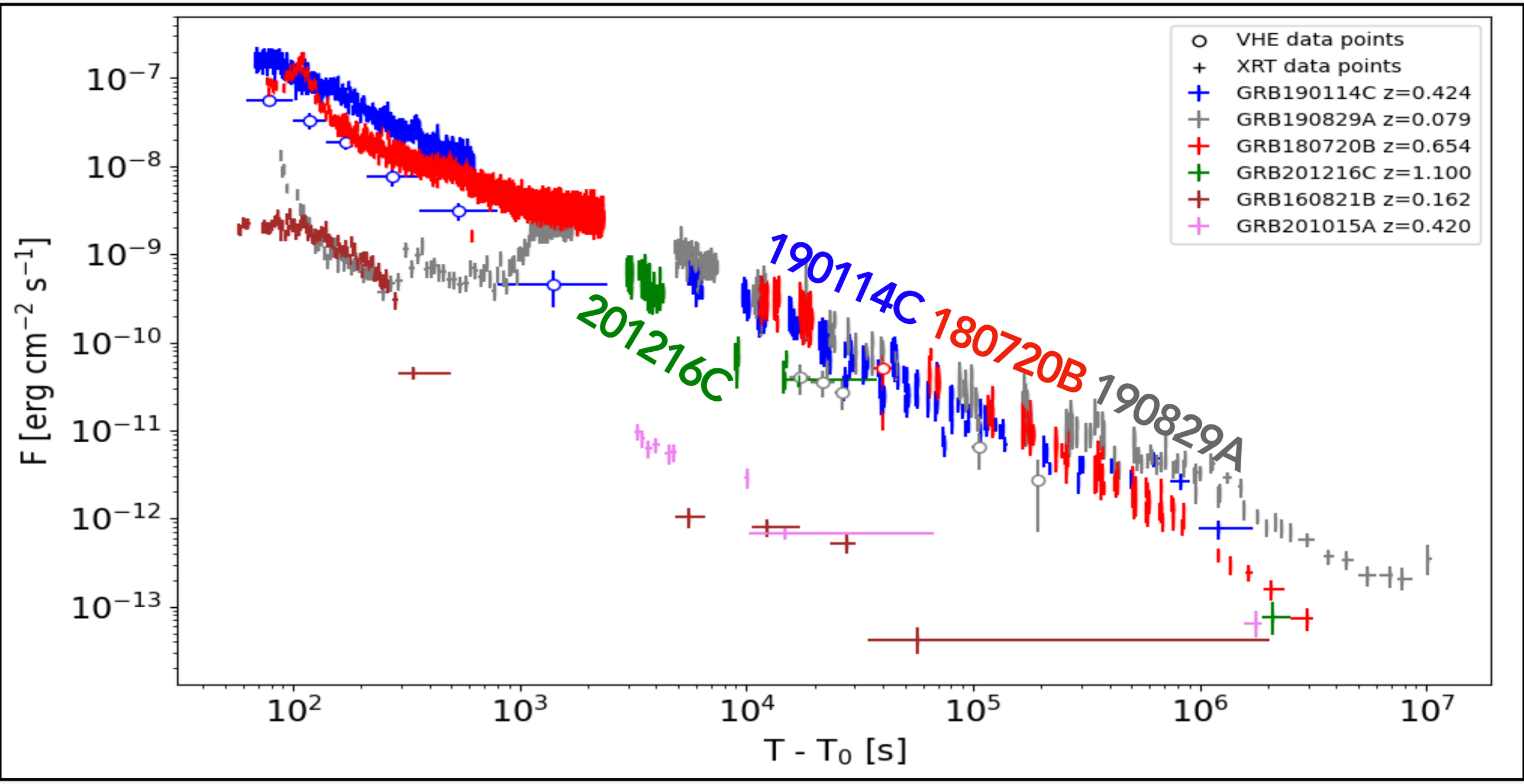
Salafia et al. 2022, ApJ, 931L, 19

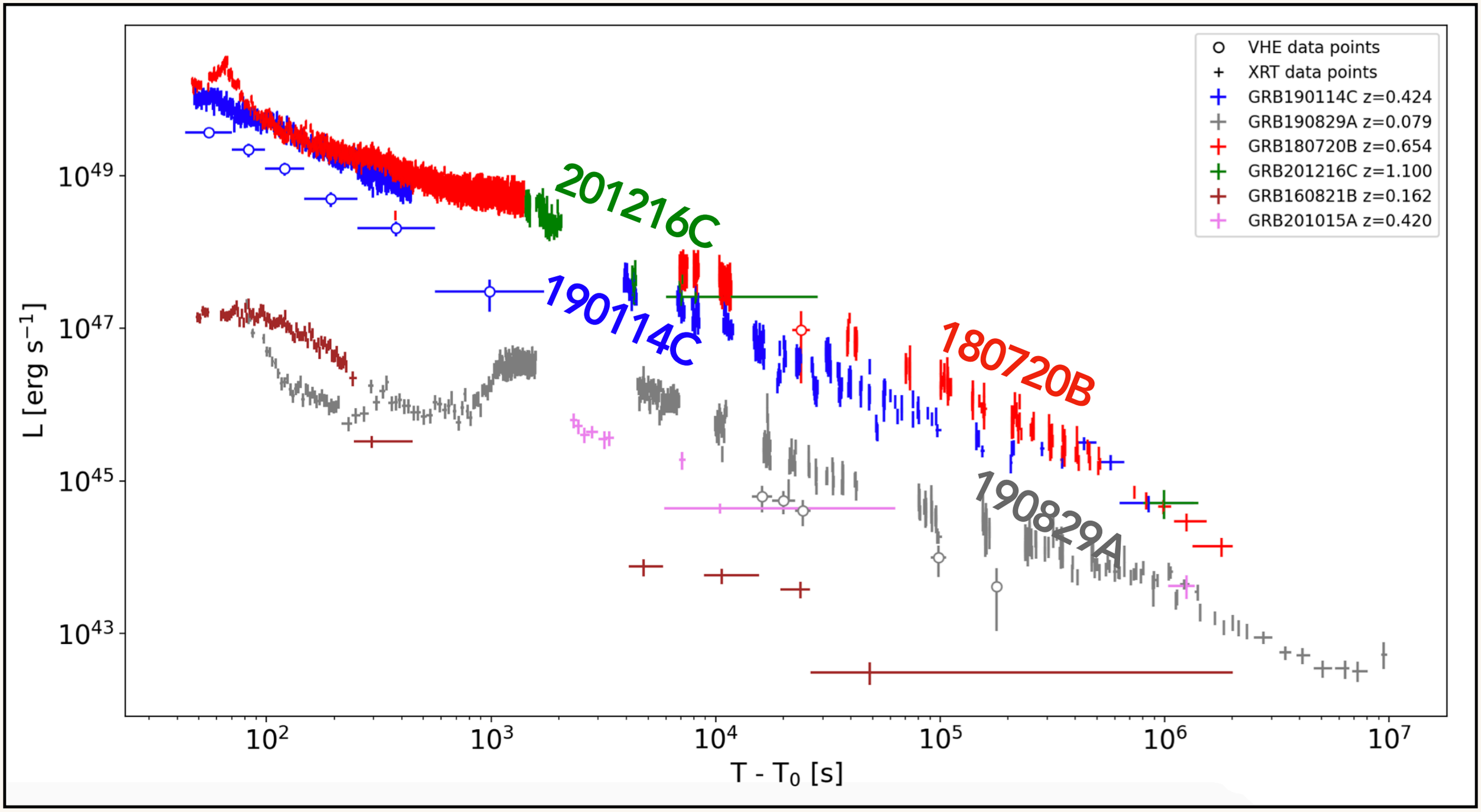


X-ray and TeV flux light curves



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

X-ray and TeV luminosity light curves



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Amati correlation

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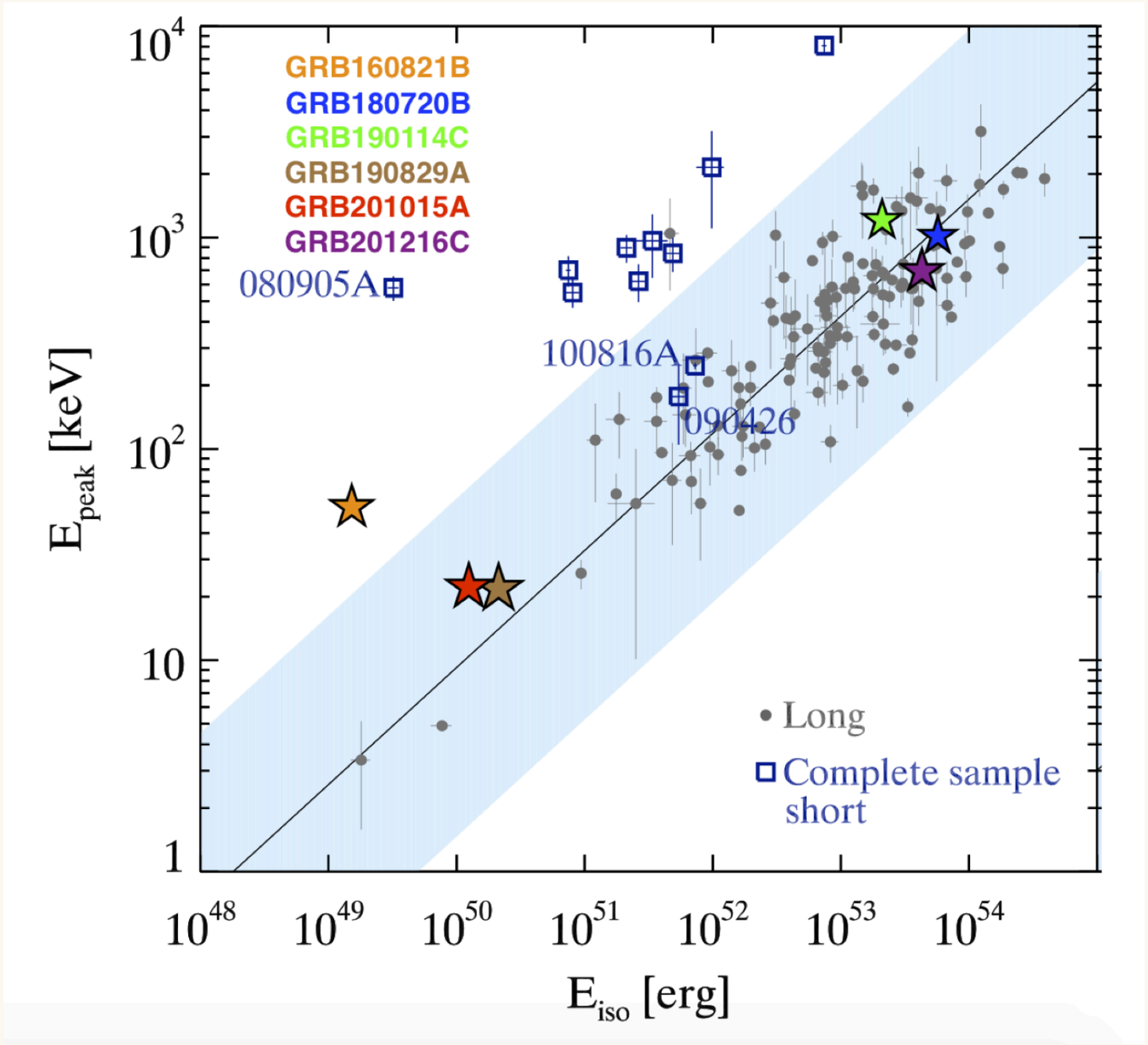


Inferred values

Table 2. GRB 190114C: parameters inferred by different authors from the modeling of observations with a synchrotron-SSC scenario.

GRB 190114C	E_k erg	ϵ_e	ϵ_B	n cm^{-3}	p	ξ_e
MAGIC Coll.	$\gtrsim 3 \times 10^{53}$	0.05–0.15	$0.05–1 \times 10^{-3}$	0.5–5	2.4–2.6	1
Wang + 2019	6×10^{53}	0.07	4×10^{-5}	0.3	2.5	1
Asano + 2020	10^{54}	0.06	9×10^{-4}	1	2.3	0.3
Asano + 2020	10^{54}	0.08	1.2×10^{-3}	0.1 (wind)	2.35	0.3
Joshi + 2021	4×10^{54}	0.03	0.012	2×10^{-2} (wind)	2.2	1
Derishev + 2021	3×10^{53}	0.1	$2–6 \times 10^{-3}$	2	2.5	1

Table 3. Parameters for modeling of GRB 190829A.

GRB 190829A	E_k erg	ϵ_e	ϵ_B	n cm^{-3}	p	ξ_e	θ_j rad
Hess Coll. (SSC)	2.0×10^{50}	0.91	$5.9–7.7 \times 10^{-2}$	1.	2.06–2.15	1.	/
Hess Coll. (Sync)	2.0×10^{50}	0.03–0.08	≈1	1.	2.1	1.	/
Salafia + 2021	$1.2–4.4 \times 10^{53}$	0.01–0.06	$1.2–6.0 \times 10^{-5}$	0.12–0.58	2.01	$<6.5 \times 10^{-2}$	0.25–0.29
Zhang + 2021	9.8×10^{51}	0.39	8.7×10^{-5}	0.09	2.1	0.34	0.1

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

Summary

WHAT HAVE WE LEARNED?

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

OPEN QUESTIONS

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

Future prospects

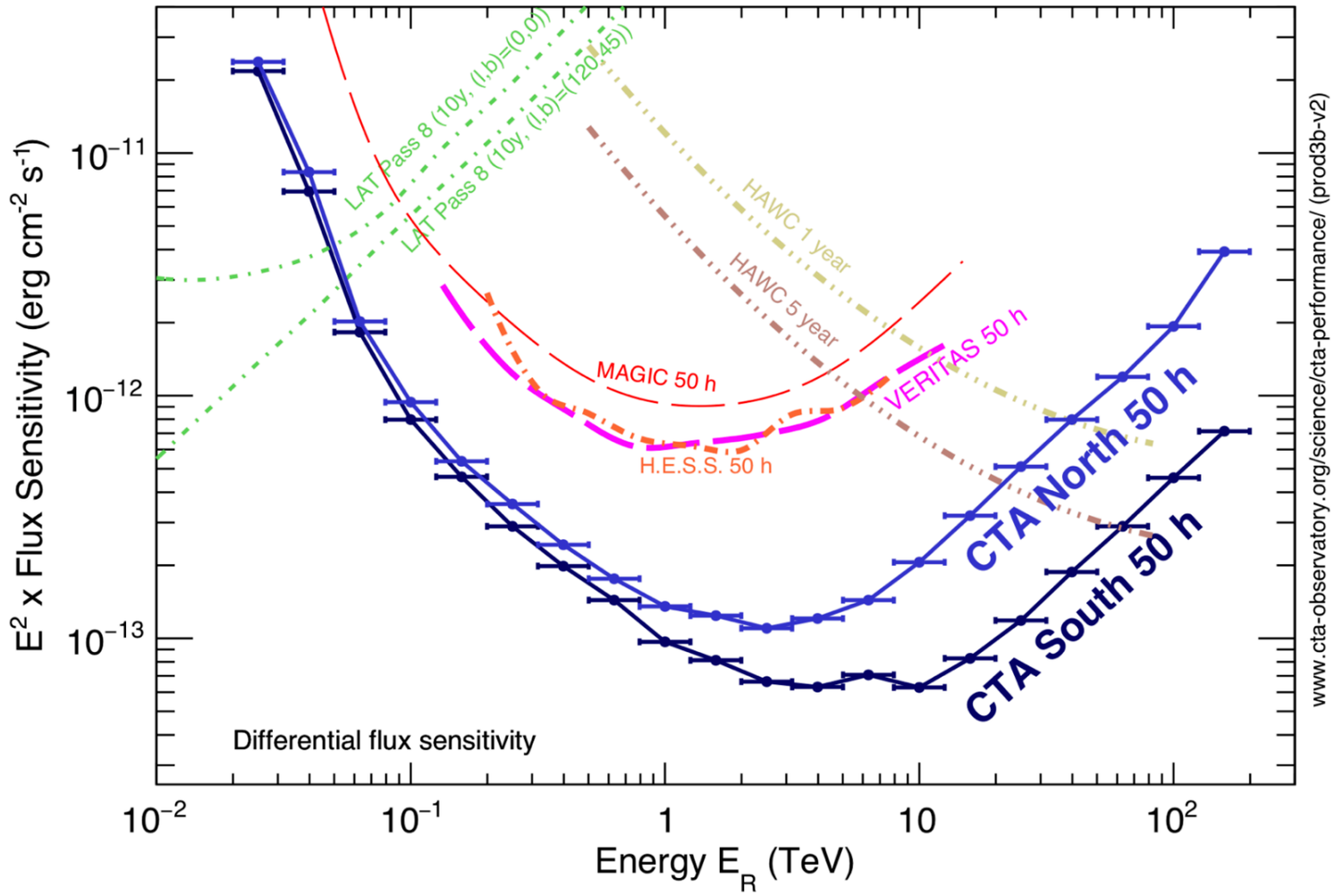
CTA - Cherenkov Telescope Array

LST: 20GeV - 3 TeV

MST: 80 GeV - 50 TeV

SST: 1 TeV - 300 TeV

CTA consortium



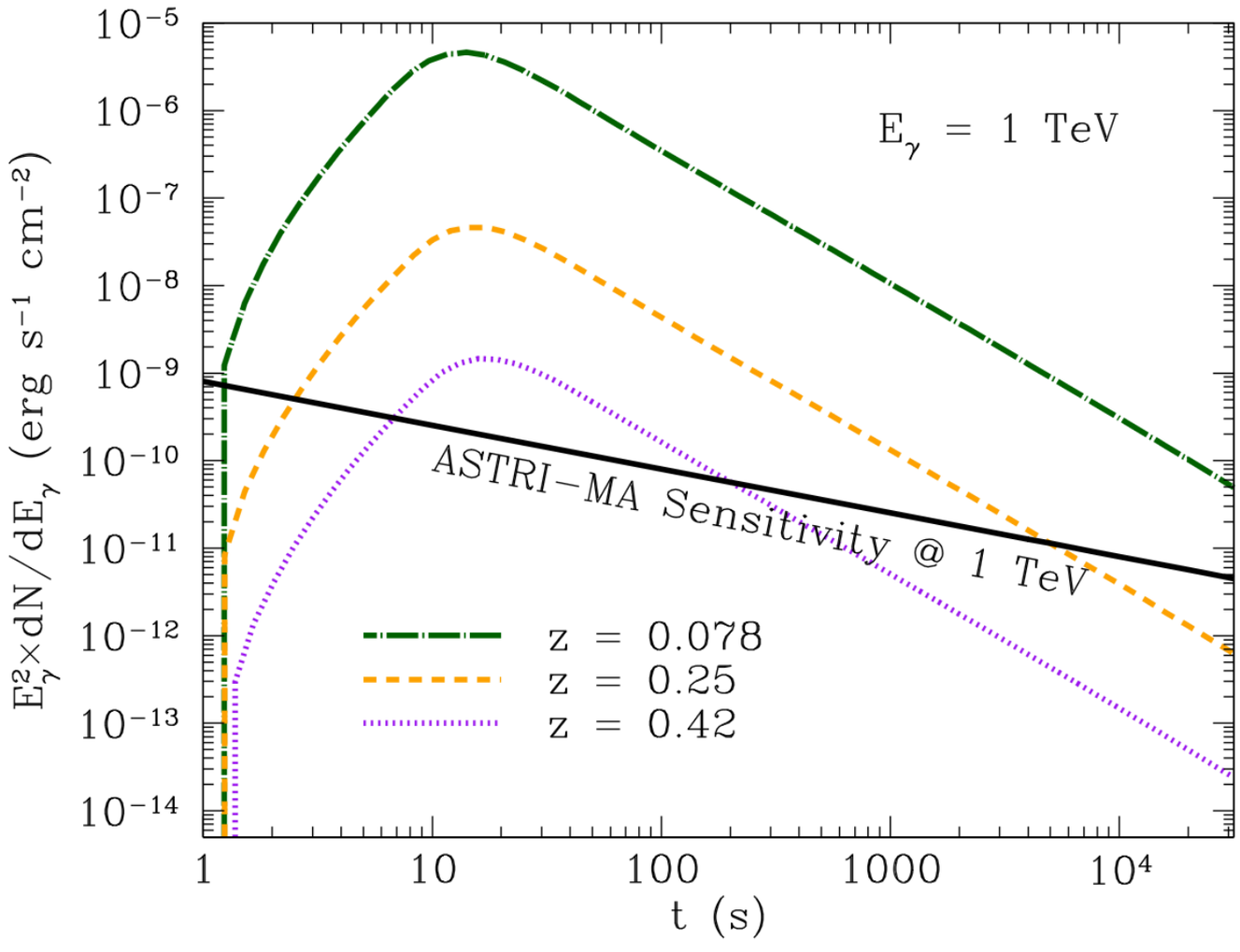
Consortium paper on prospects for CTA observations of GRB in preparation

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., JHEAp, 35, 1 (2022)

ASTRI Mini-Array core science at the Observatorio del Teide

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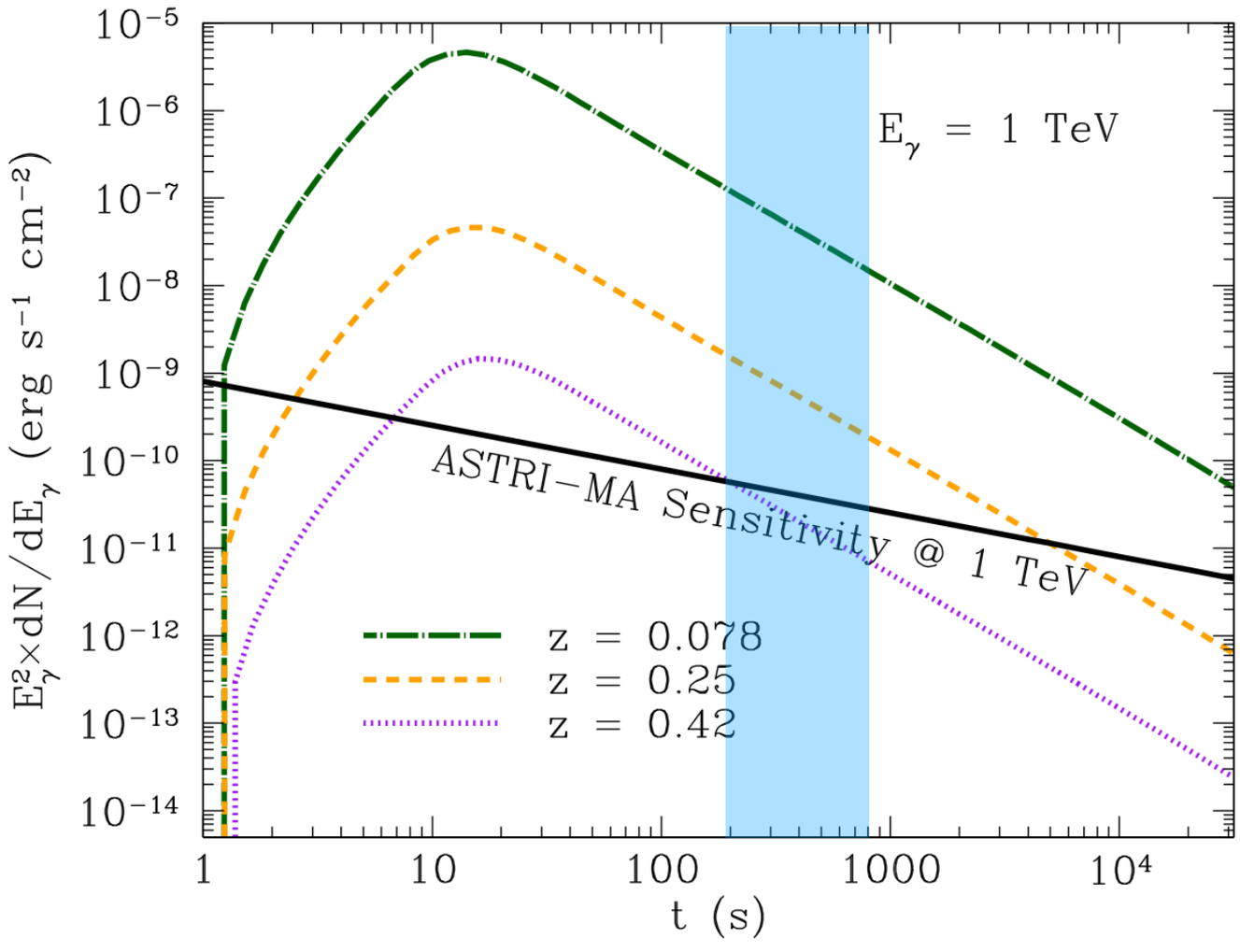

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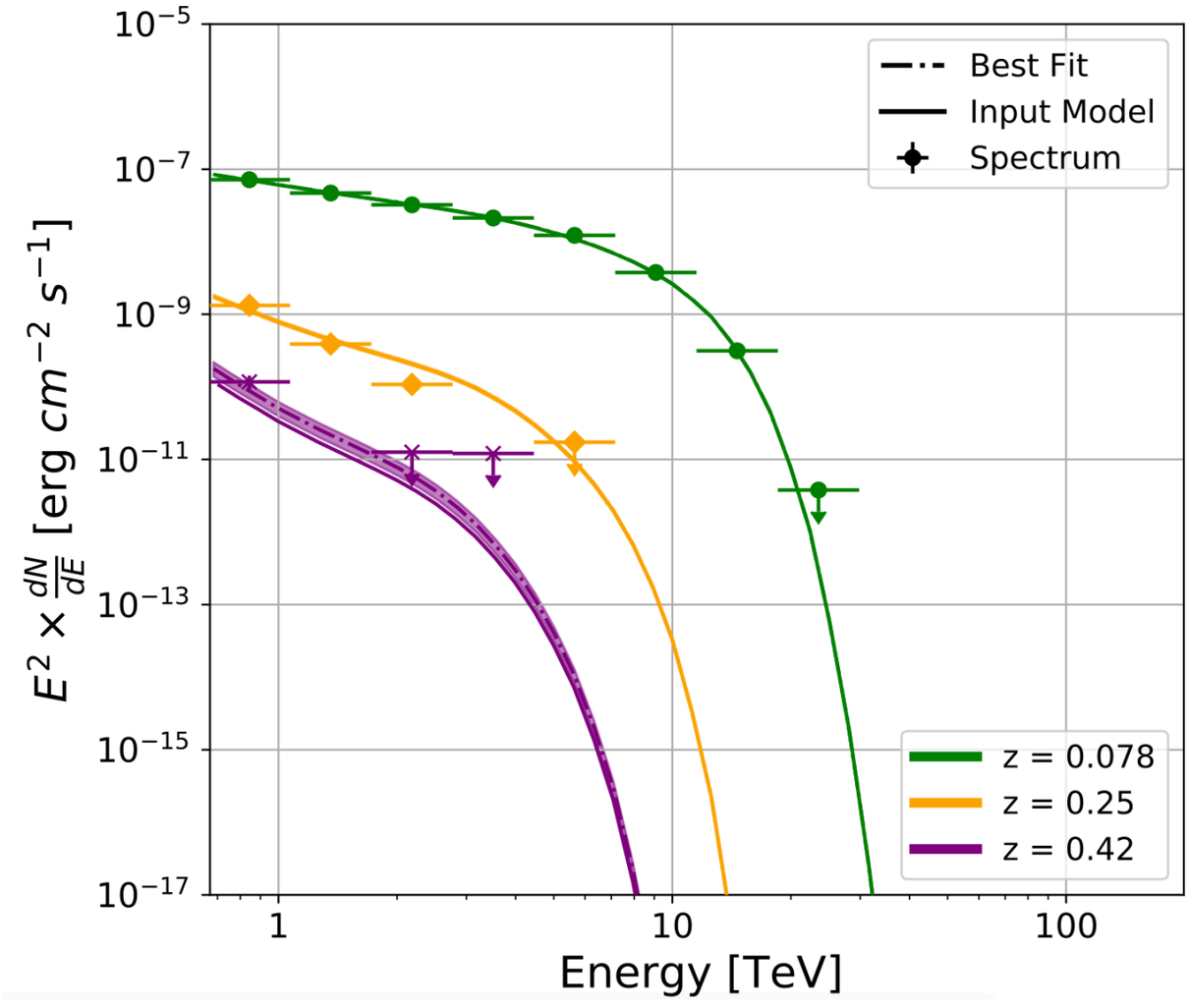

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Thank you for your attention

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