GRBs at VHE:

What have we learned so far

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TeV detections by IACTs

A summary

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

	T_{90} s	$E_{\gamma,iso}$ erg	z	T_{delay} s	E_{range} TeV	IACT (sign.)
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)
221009A	600	3×10^{54}	0 .15	0	0.5-18	LHAASO

significance < 5σ

significance > 5σ

MAGIC GRB 190114C

Lightcurve

z = 0.42

long GRB

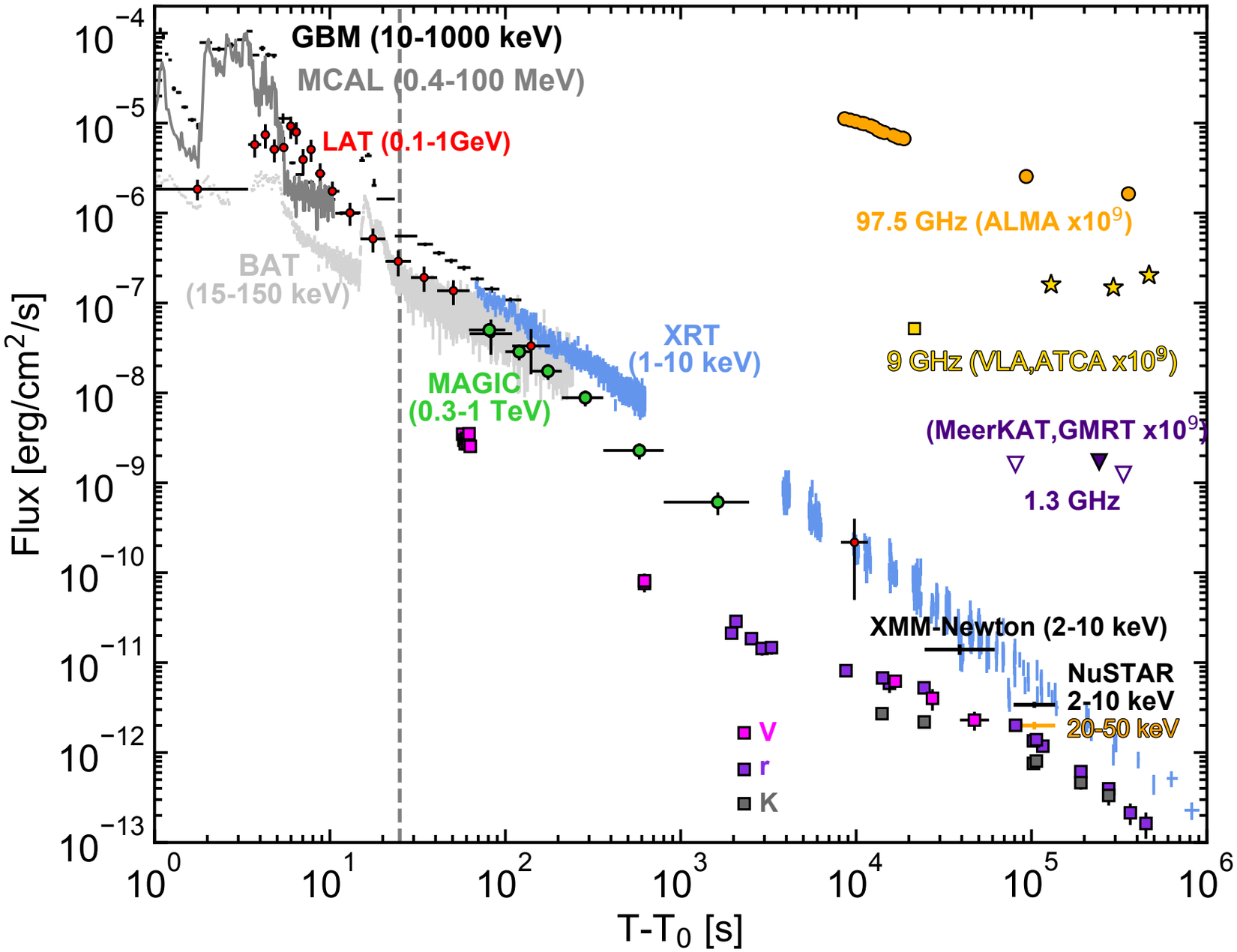
E_{iso} = 2.5 x 10^{53} erg

MAGIC detection:

1-40 minutes after the GRB

in the energy range 0.3-1 TeV

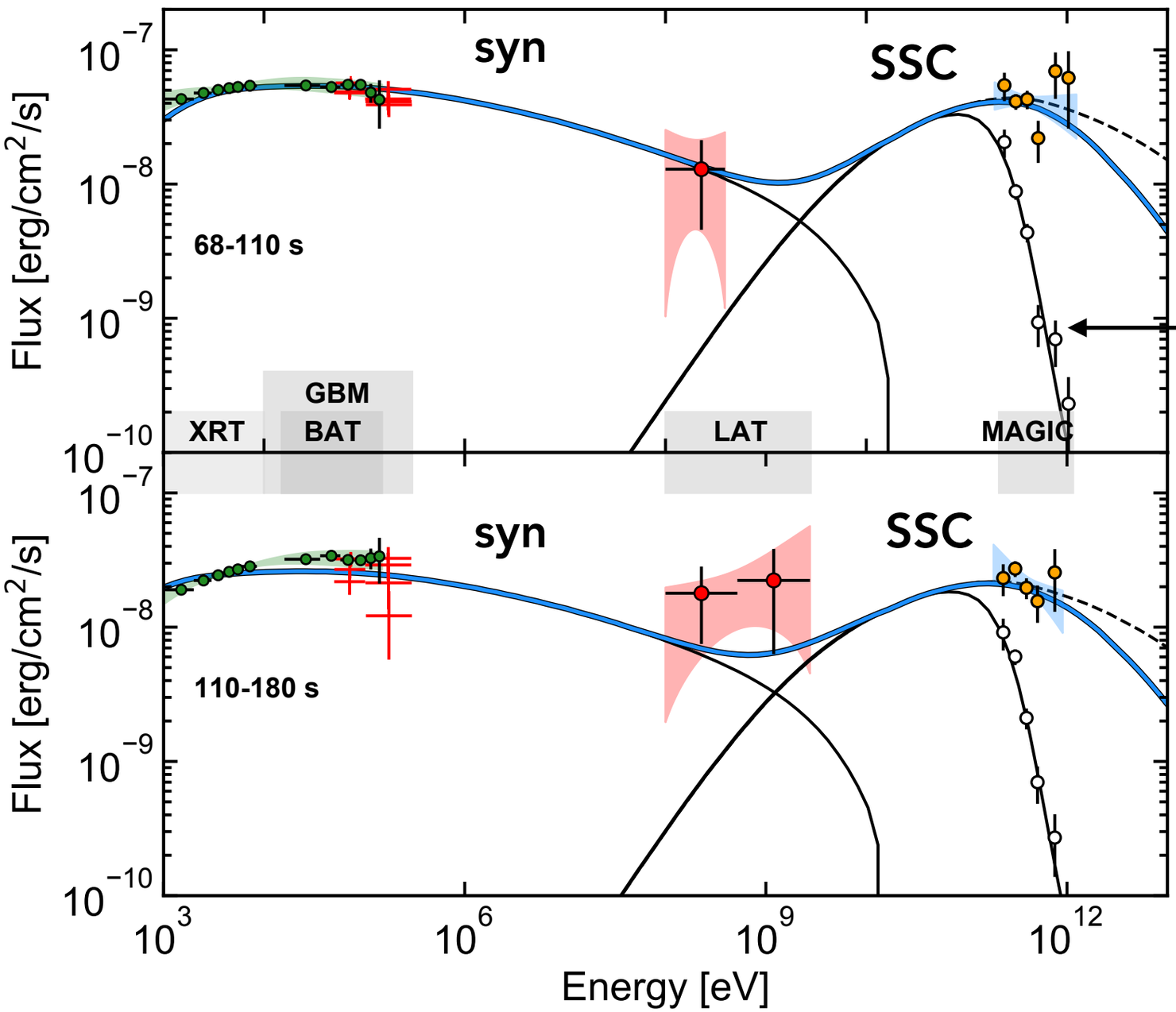
MAGIC Collab, 2019, Nature, 575, 459



MAGIC GRB 190114C

SED modeling: double peak

MAGIC Collab, 2019, Nature, 575, 459



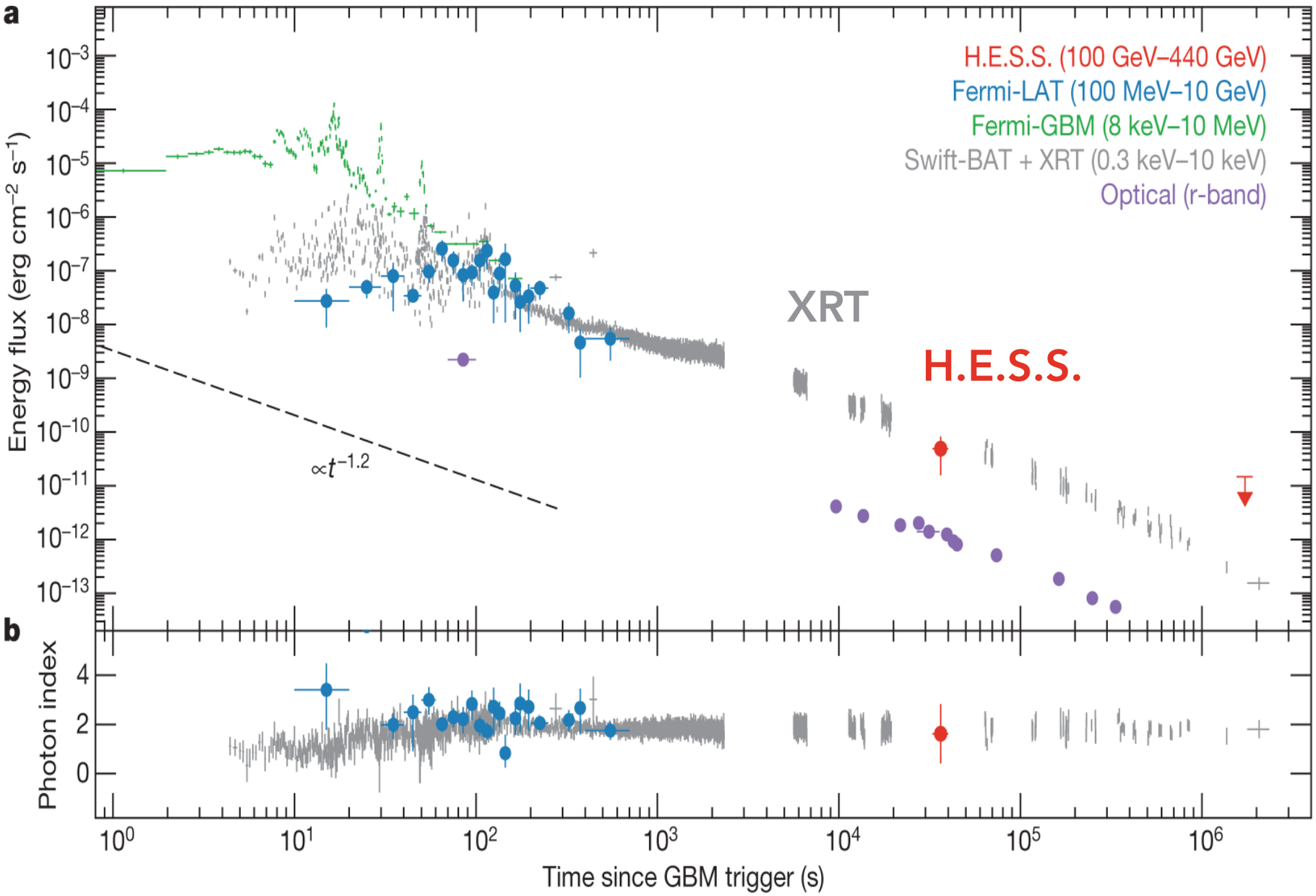
internal absorption

observed spectrum (EBL absorbed)

H.E.S.S. GRB 180720B

Lightcurve

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



General properties

z=0.65

long GRB

E_{pr} = 6 x 10^{53} erg

H.E.S.S. detection

100-440 GeV

photon index:

-1.6+-0.4

H.E.S.S. GRB 190829A

Lightcurve

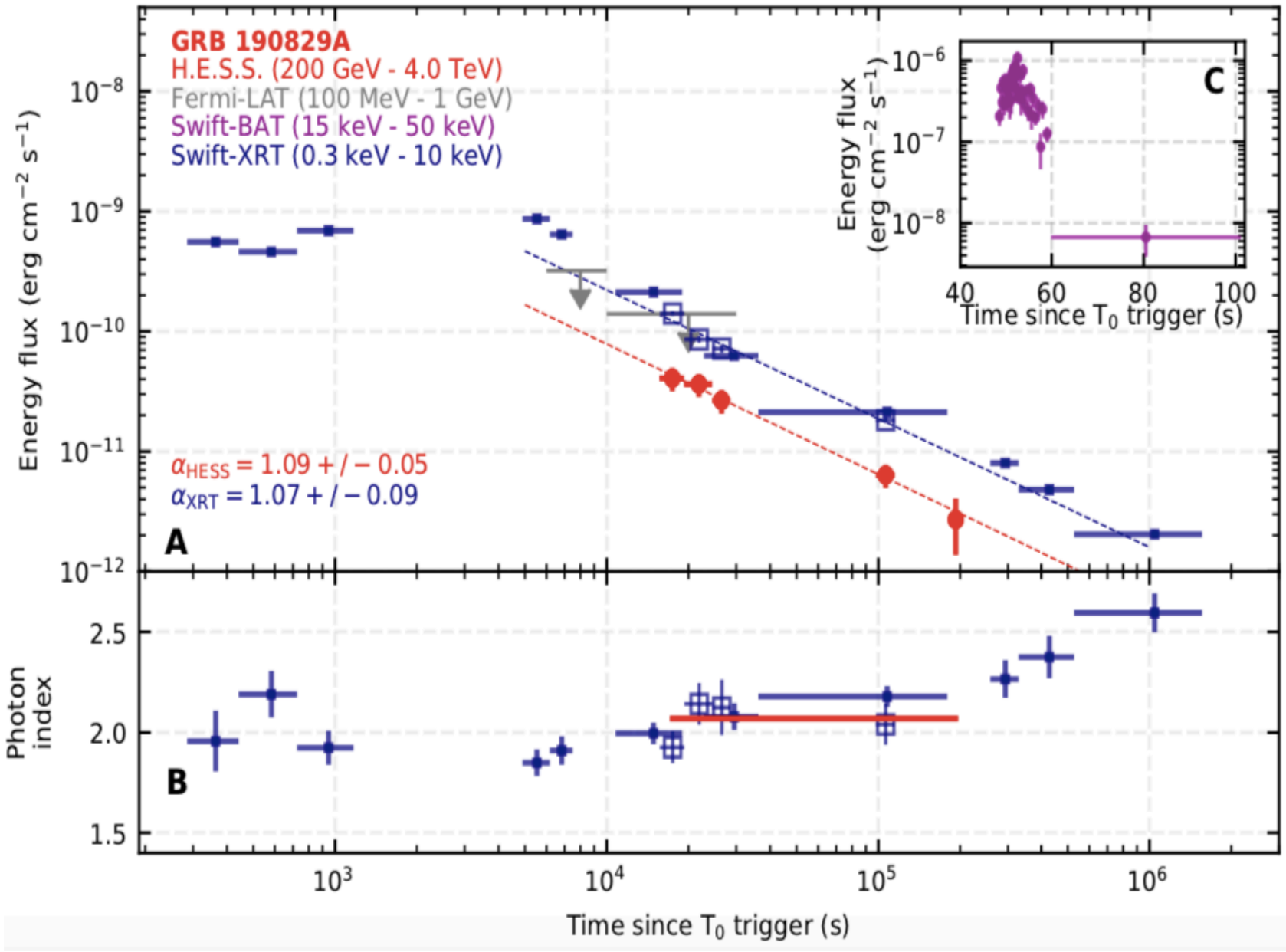
H.E.S.S. Collab, 2019, Nature, 575, 464

General properties

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

HESS detection

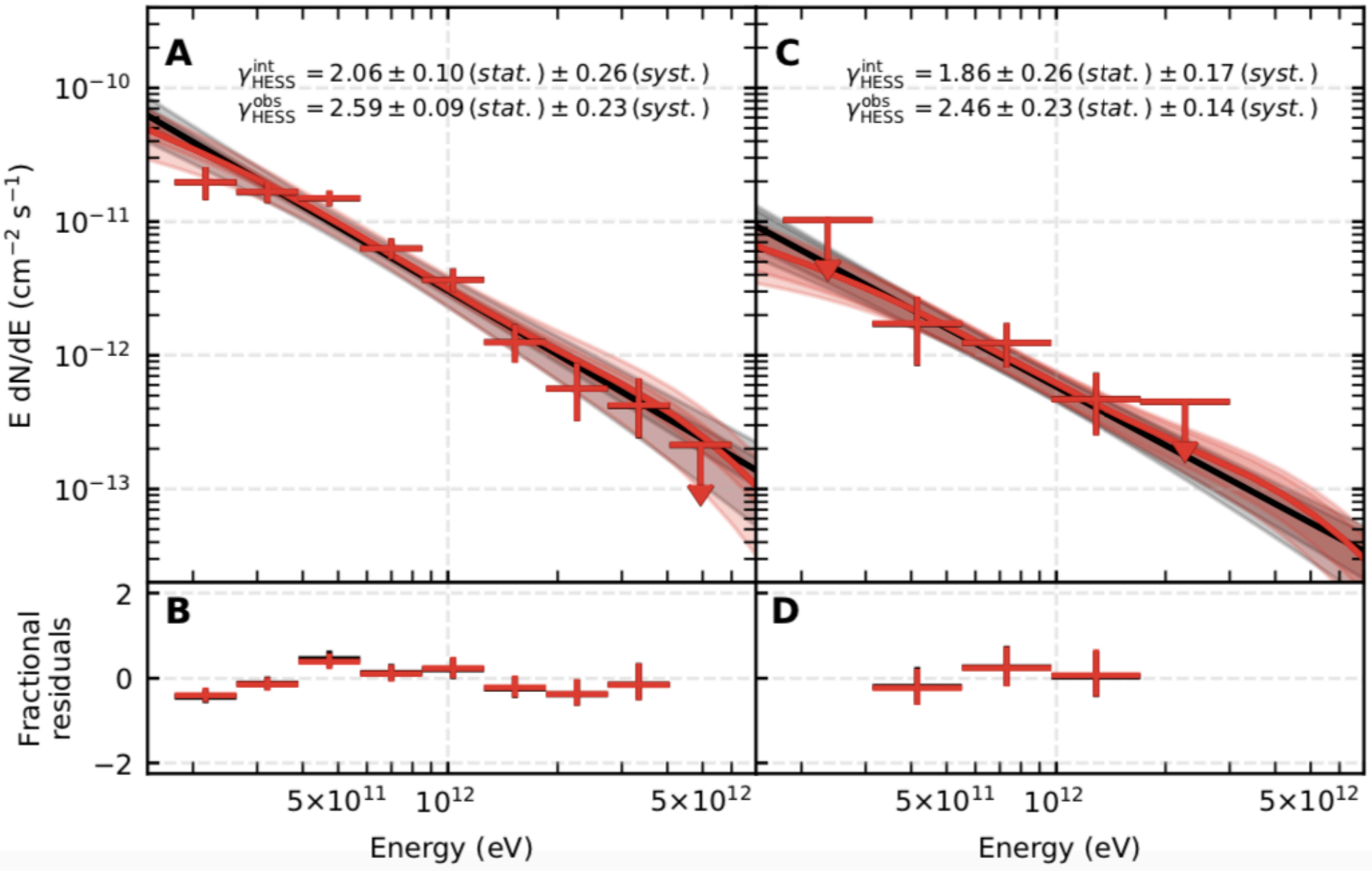
- ~4 hours to 3 days
- in the energy range 0.2 - 3.3 TeV



H.E.S.S. GRB 190829A

Spectra

H.E.S.S. Collab, 2021, Science, 372, 6546



LHAASO GRB 221009A

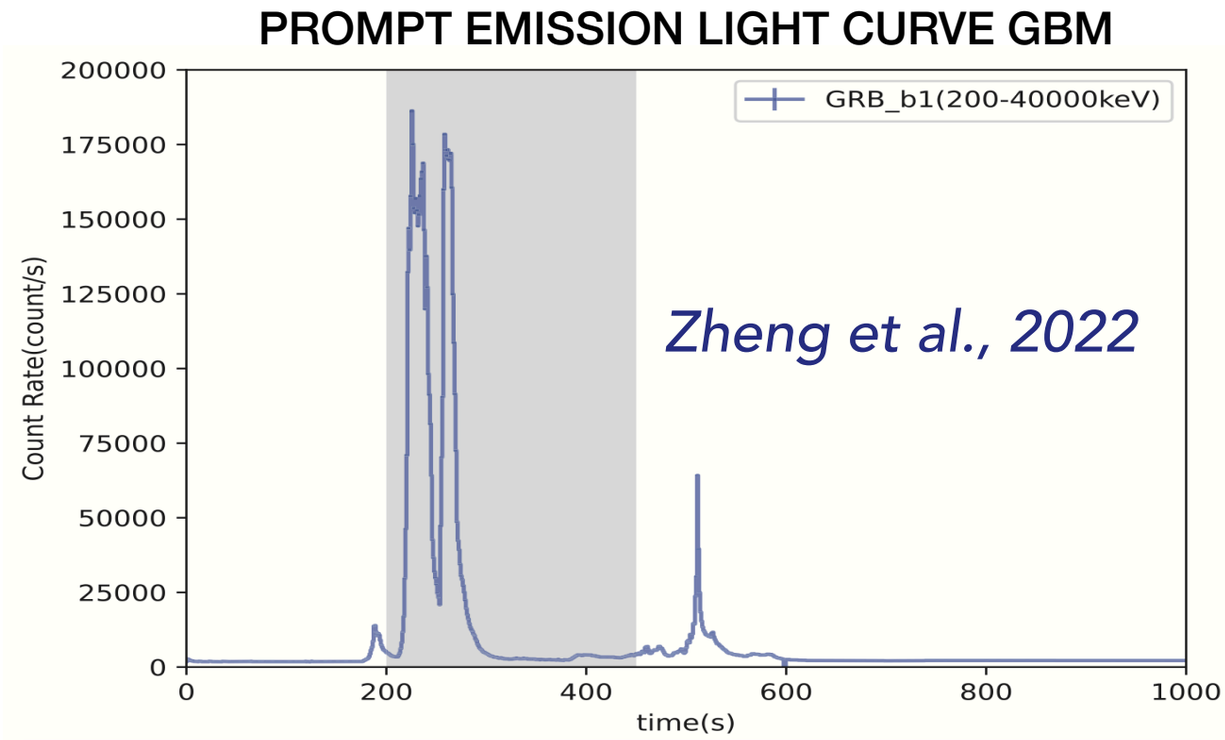
An intrinsically luminous GRB at z = 0.15

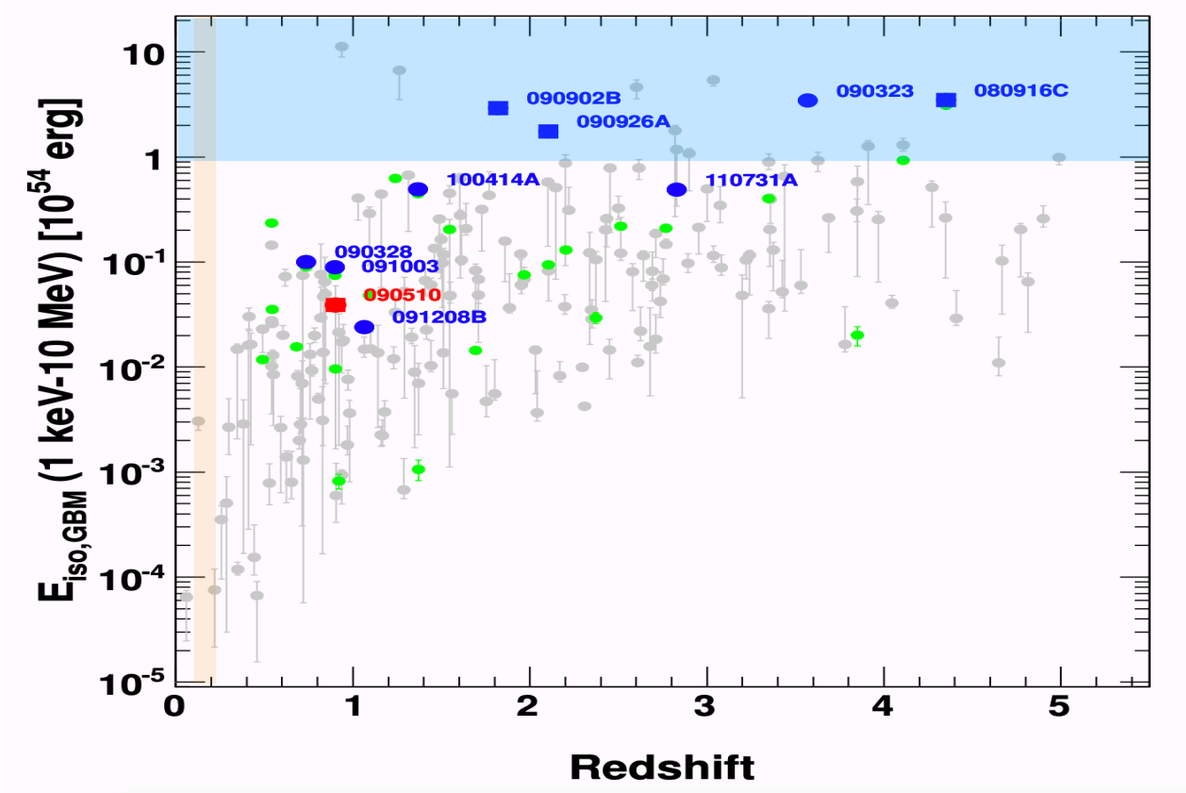
PROMPT

- GBM saturated
- LAT pile-up
- E_{iso} ~ 10^{54} - 10^{55} erg
- L_{iso} ~ 10^{53} erg/s
- Duration ~ 600 s (long GRB)

Large energetics + low redshift

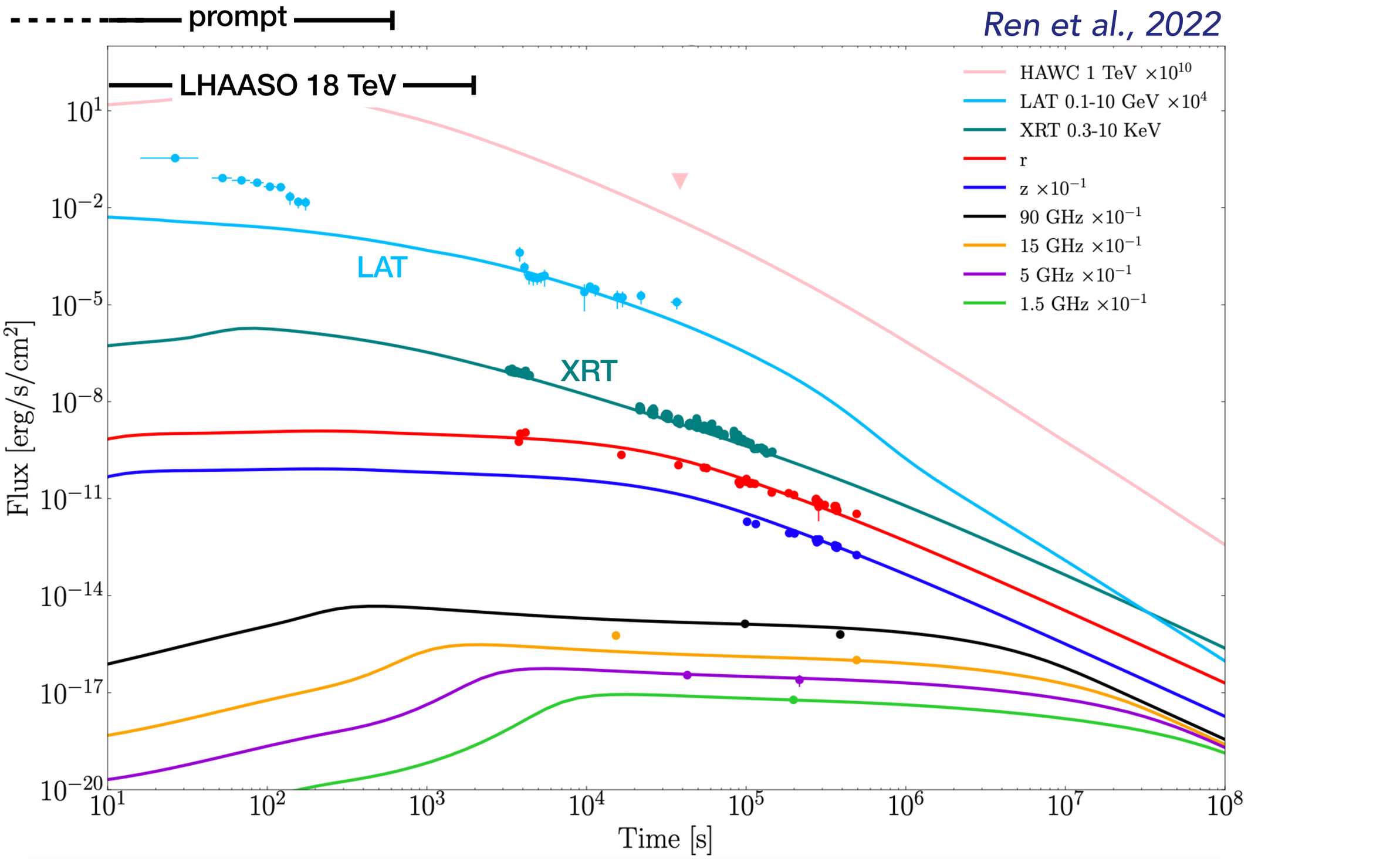
—> very rare event!





GRB 221009A

LHAASO in the first 2000 s >5000 photons above 0.5 TeV, max photon energy 18 TeV



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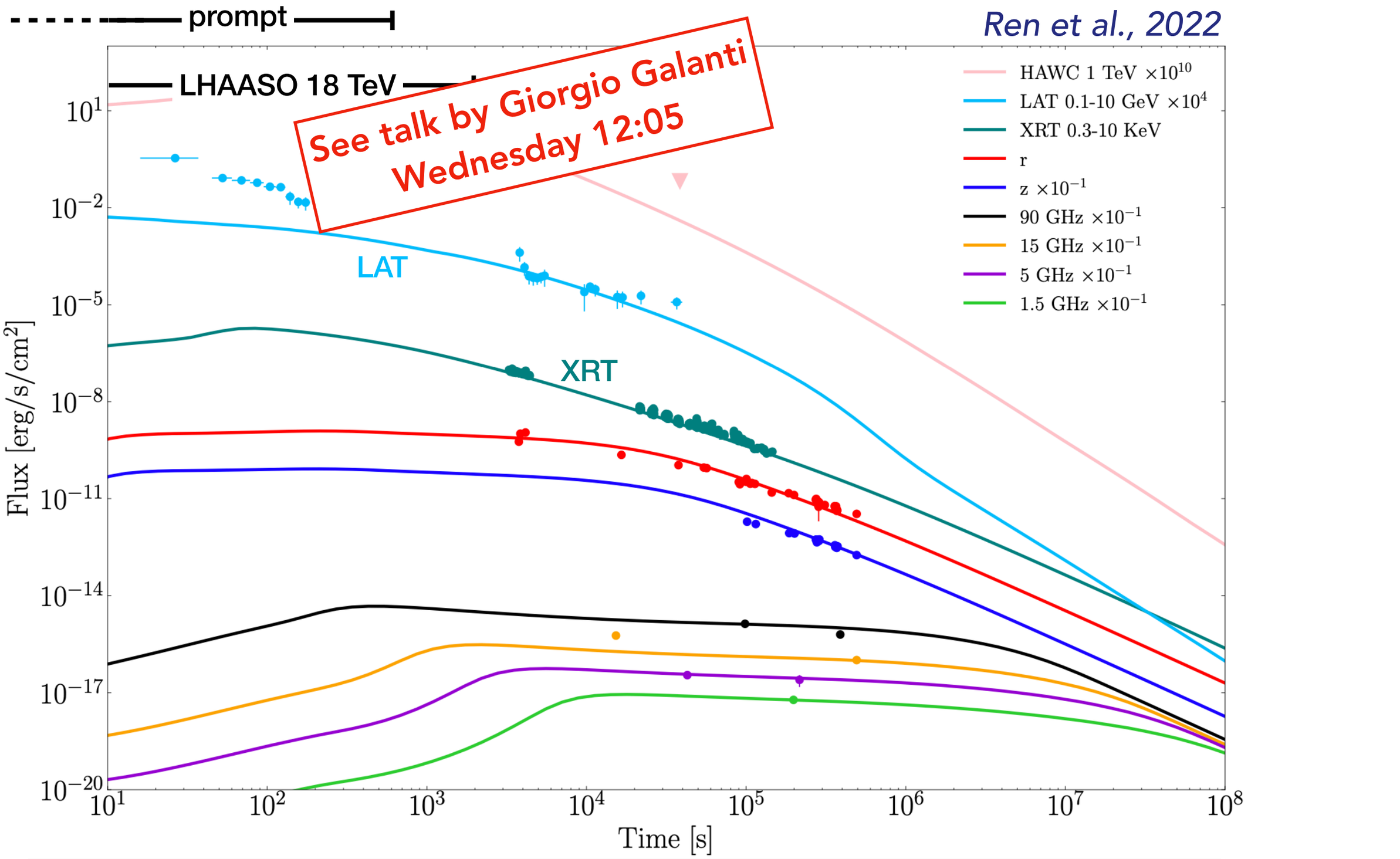

WHAT HAVE WE LEARNED

MODEL - INDEPENDENT CONSIDERATIONS

- Even not particularly bright GRBs produce TeV radiation

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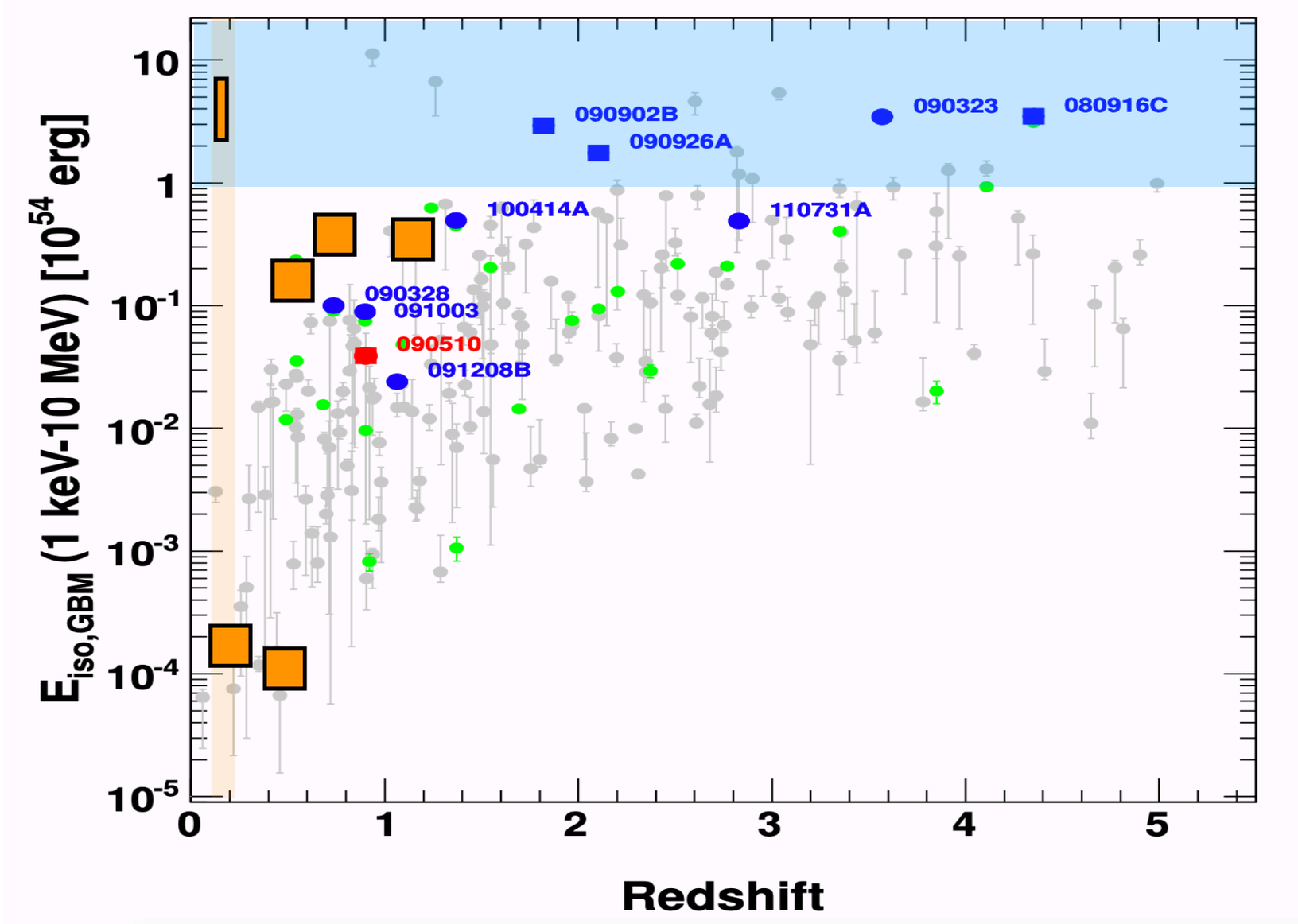

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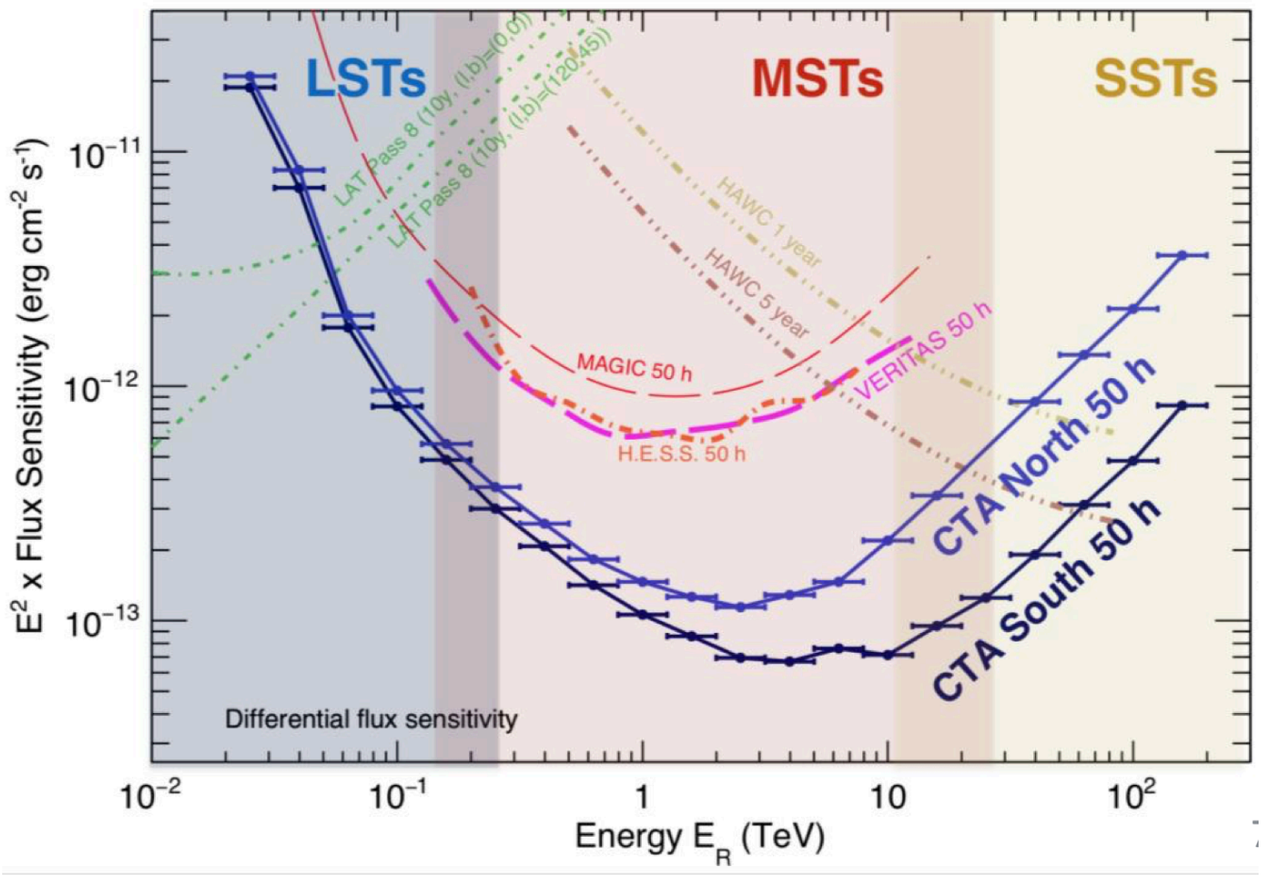

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- TeV emission is associated to afterglow radiation
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- Concrete possibility to use GRBs for fundamental physics and EBL studies

See talk by Giorgio Galanti
Wednesday 12:05

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MODEL - INDEPENDENT CONSIDERATIONS

- Even not particularly bright GRBs produce TeV radiation
- TeV emission is associated to afterglow radiation
- TeV emission can last days
- TeV emission can extend to energies > 10 TeV
- Concrete possibility to use GRBs for fundamental physics and EBL studies
- Energy in TeV similar to energy in X-ray —> doubles the energy released in the afterglow phase

WHAT HAVE WE LEARNED

MODEL - DEPENDENT IMPLICATIONS

- In external shocks there are conditions for SSC. This implies an equipartition value for B lower then usually assumed (10^{-4} instead of 10^{-2}-10^{-1})

- SSC peak flux similar to synchrotron peak flux —> Compton param ~1
  —> affects the location of the synchrotron cooling frequency

- Parameter space reduced —> degeneracy among parameters reduced

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

Open questions & Future challenges

- Which conditions are required to produce VHE component?

- How common are these conditions?

- VHE emission in short GRBs: understand differences short/long (environment, jet,…)

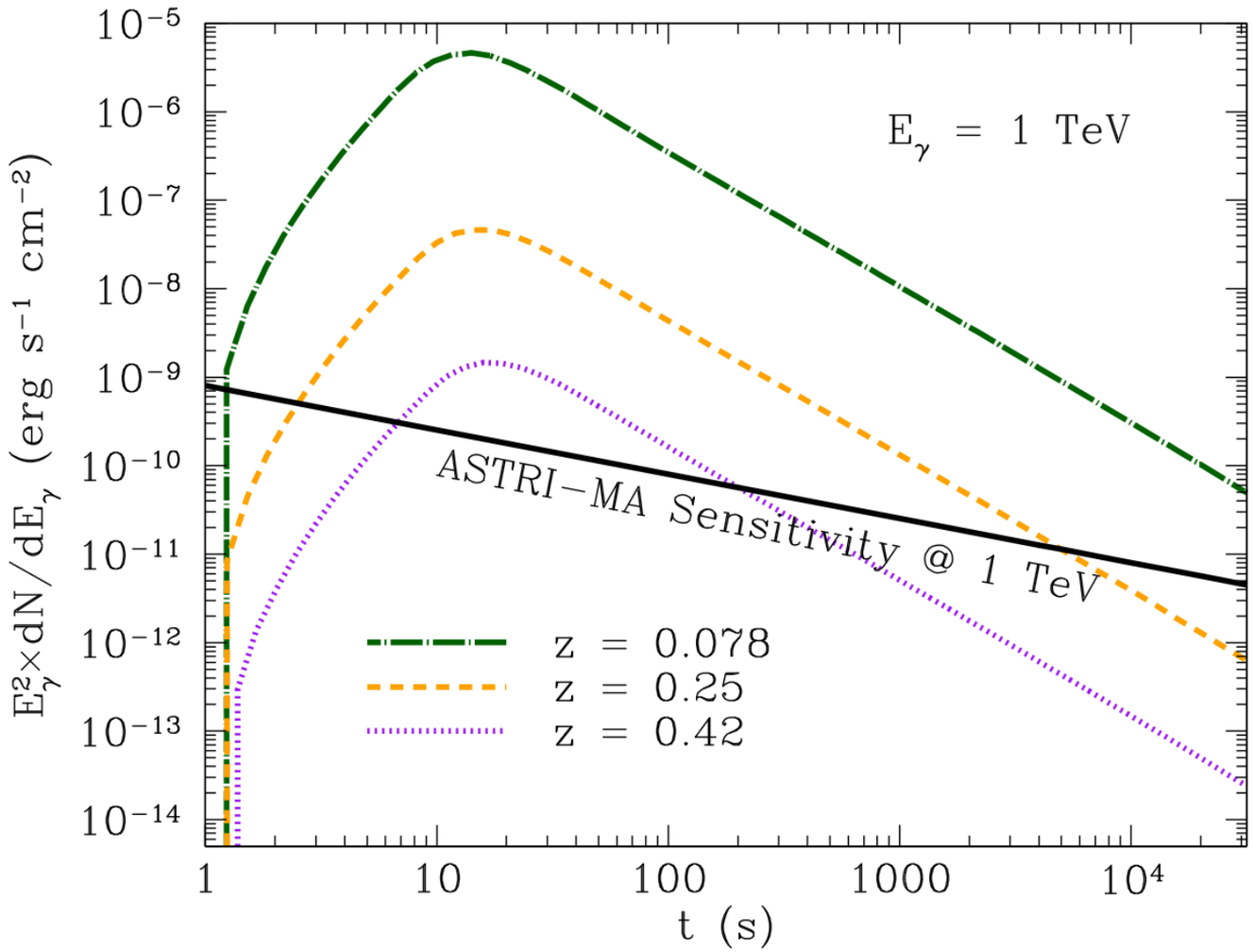
- VHE observations during the prompt: unique tool to understand the origin of prompt radiation (see LHAASO detection)

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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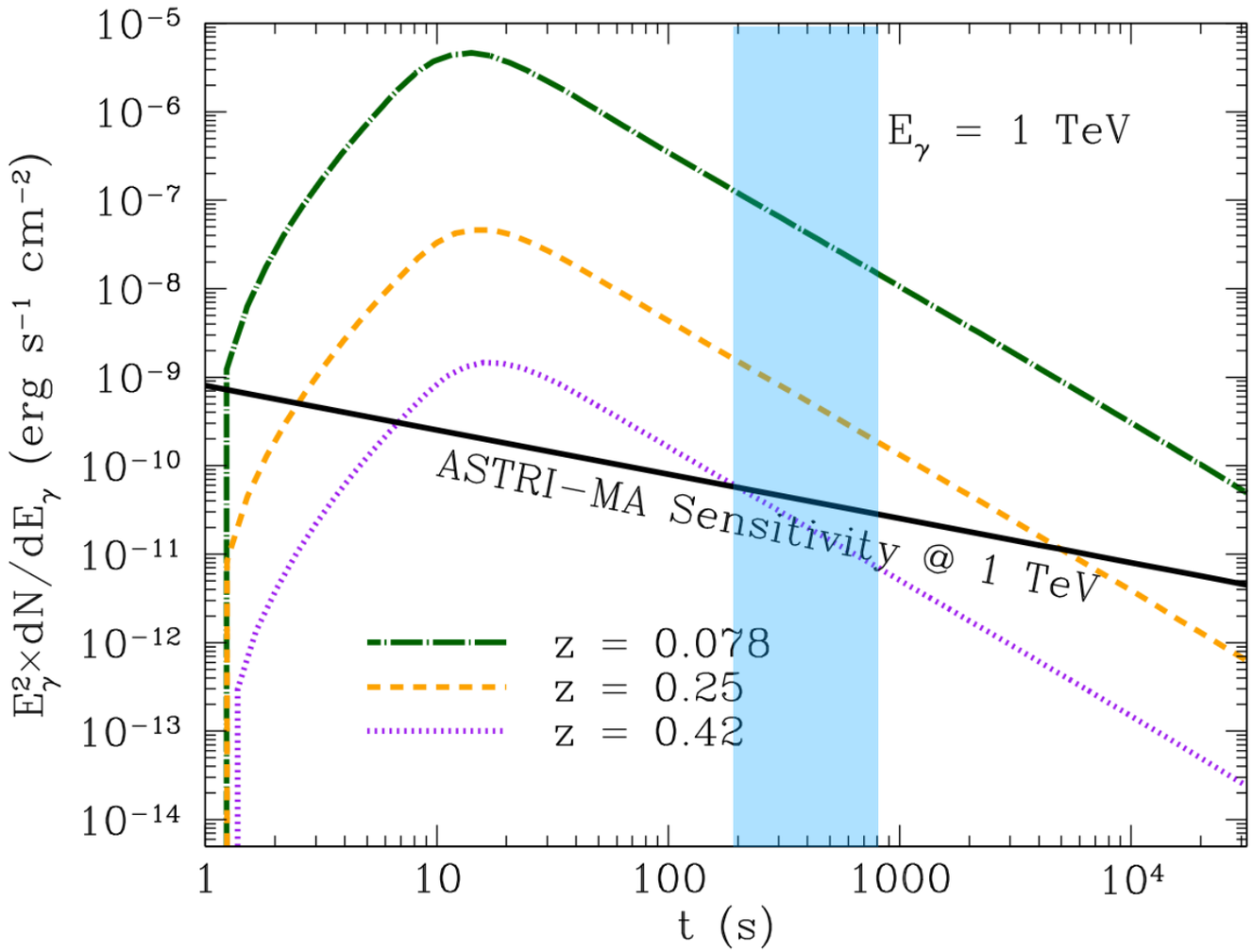

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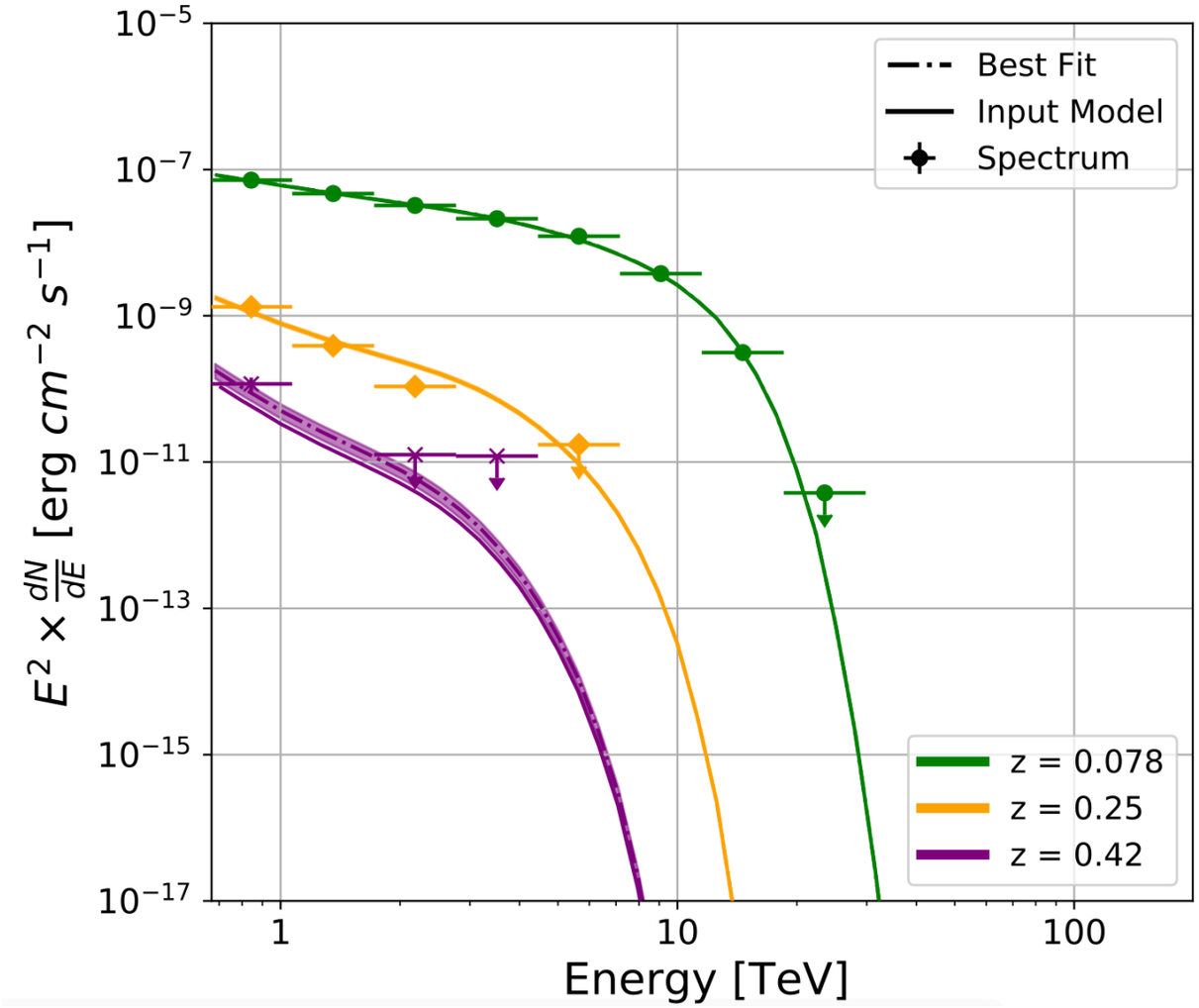

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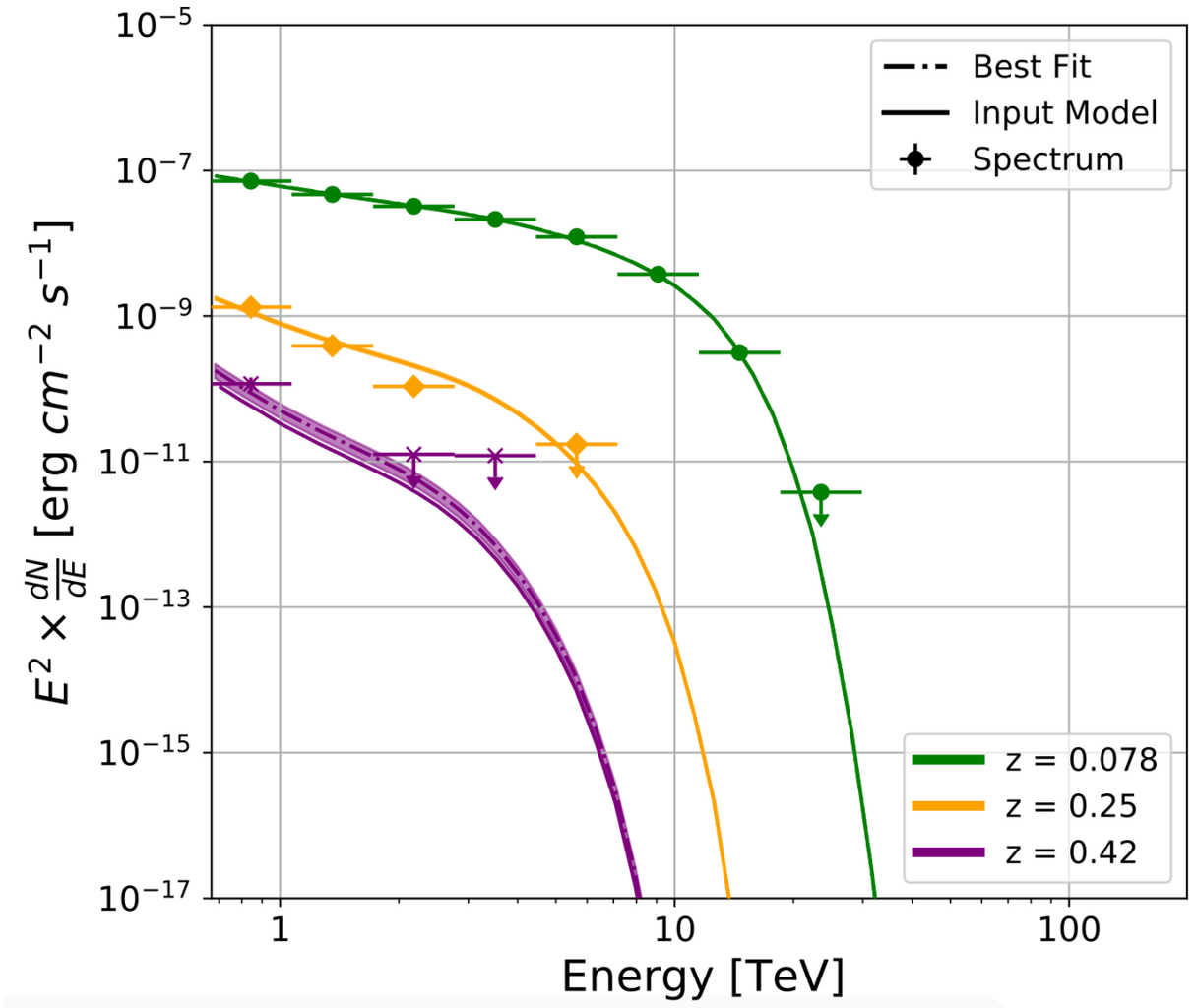

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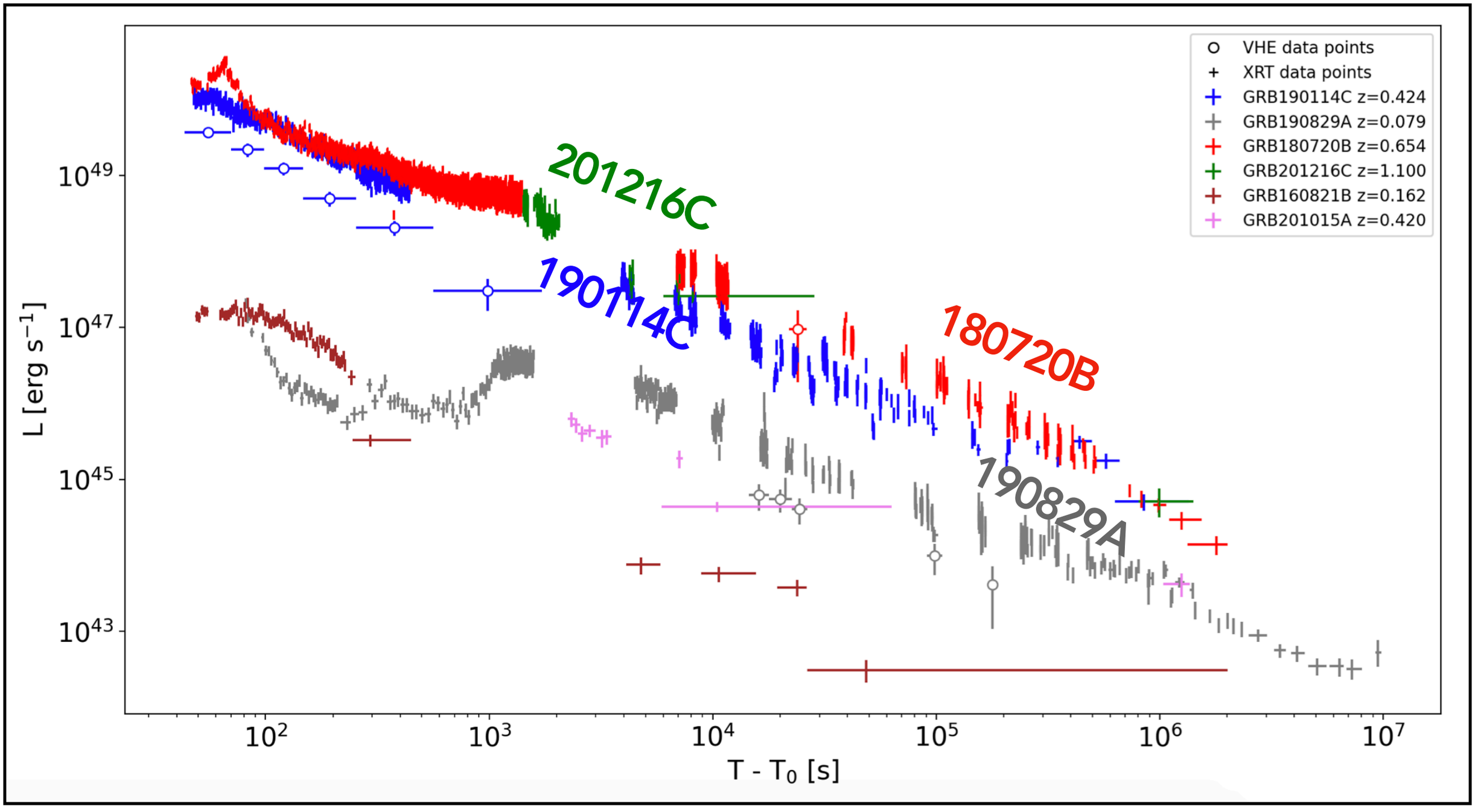
THANK YOU FOR YOUR ATTENTION

X-ray and TeV luminosity light curves



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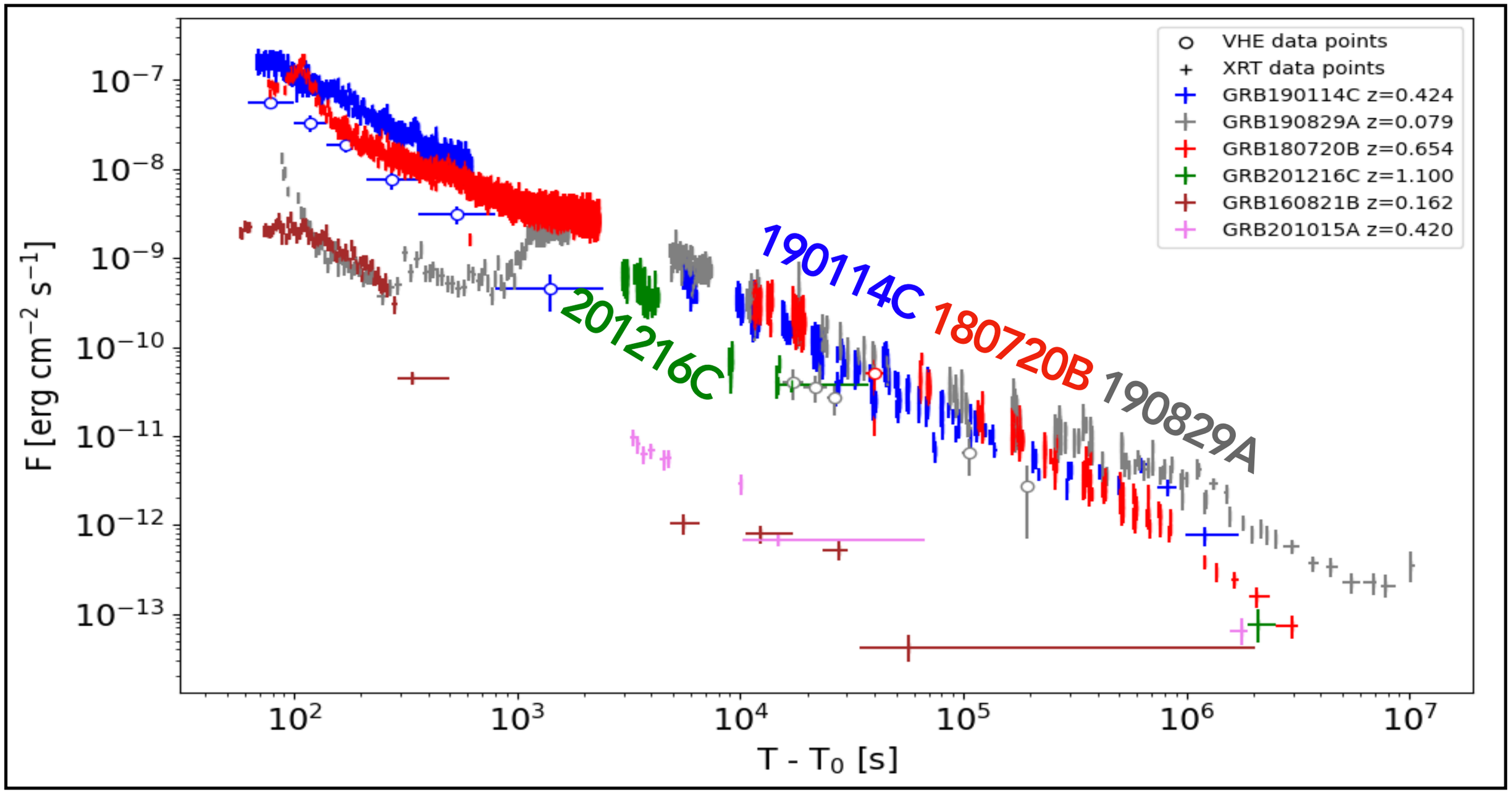
X-ray and TeV flux light curves



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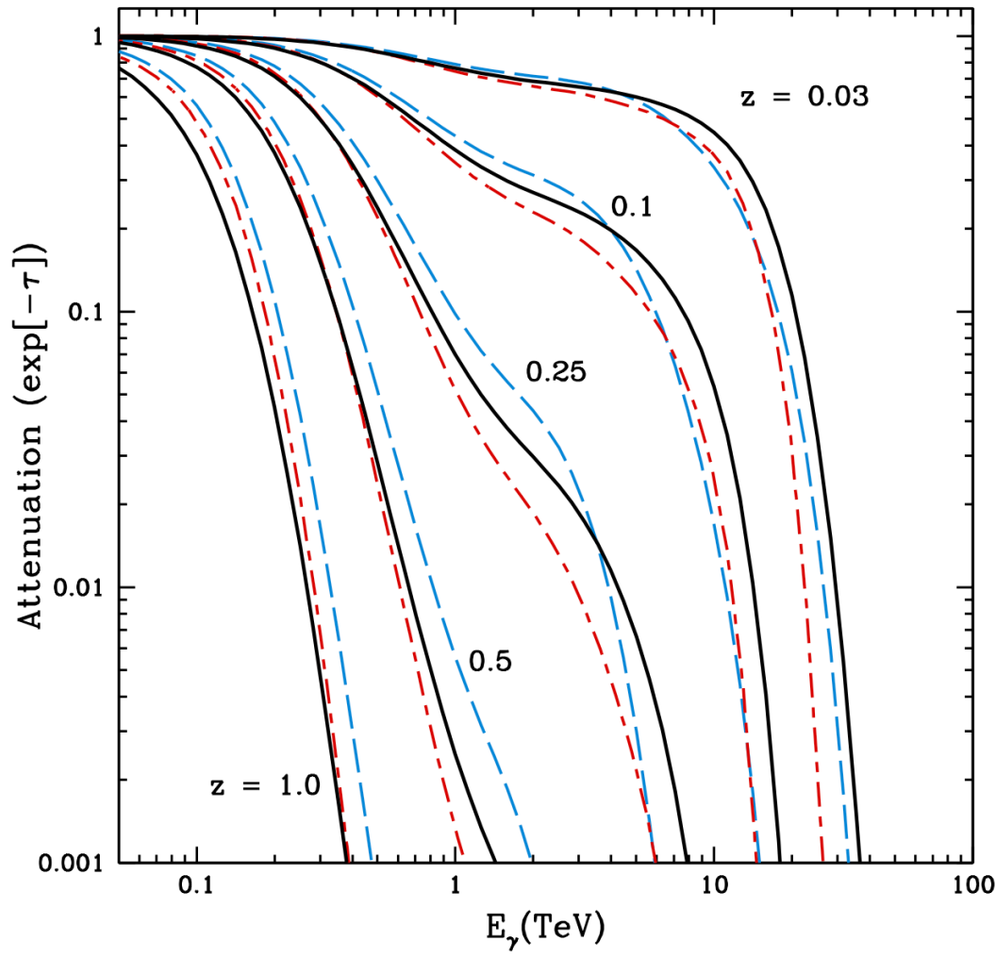
EBL: EXTRAGALACTIC BACKGROUND LIGHT

VHE photons coming from cosmological distances are attenuated by pair production with EBL photons

$$\gamma\,\gamma_{EBL} \rightarrow e^{+}e^{-}$$

Amount of attenuation depends on photon energy and redshift

Gilmore et al., 2012



Dominguez EBL model

Gilmore EBL model

TeV detections by IACTs

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

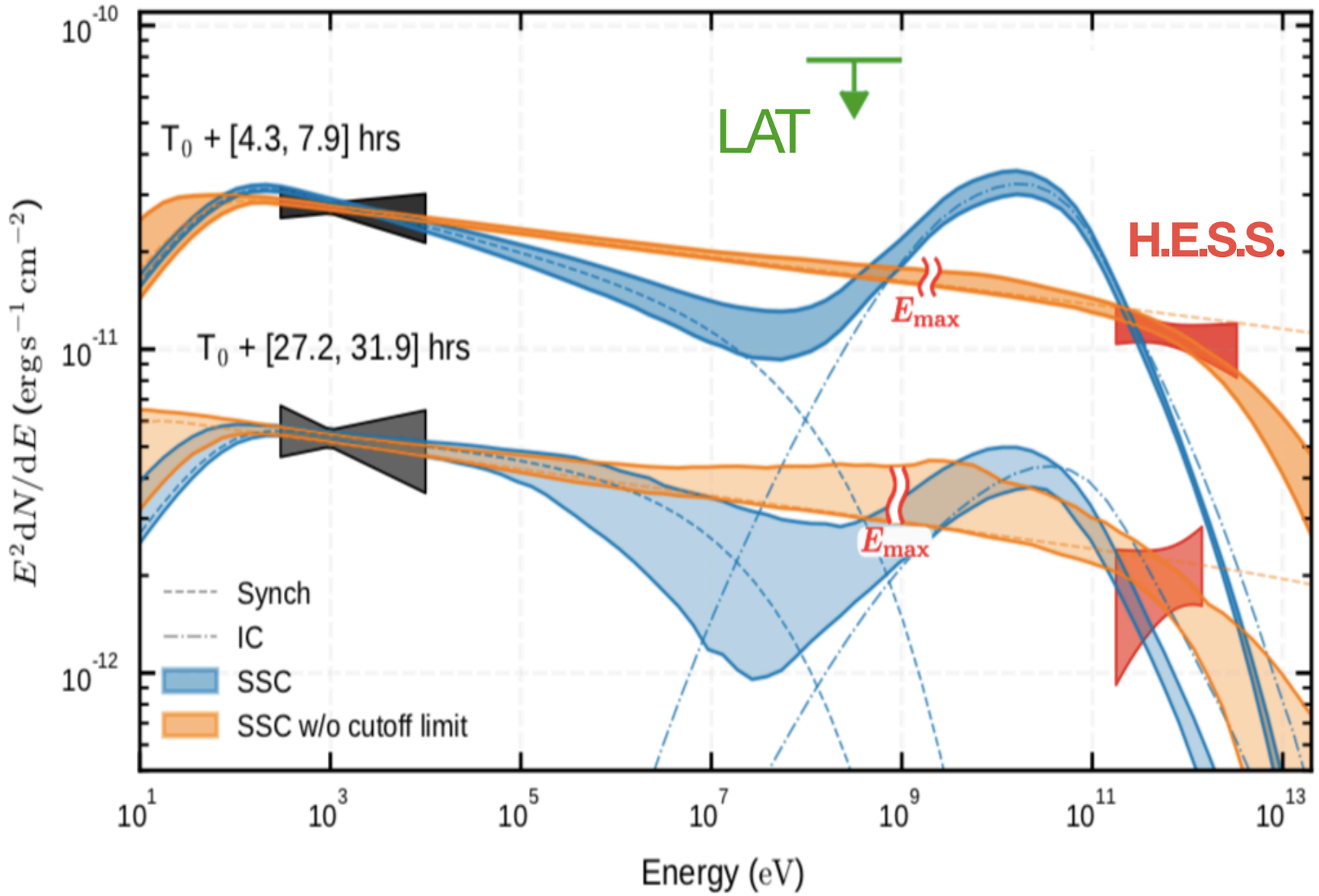
H.E.S.S. Collab, 2019, Nature, 575, 464

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



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

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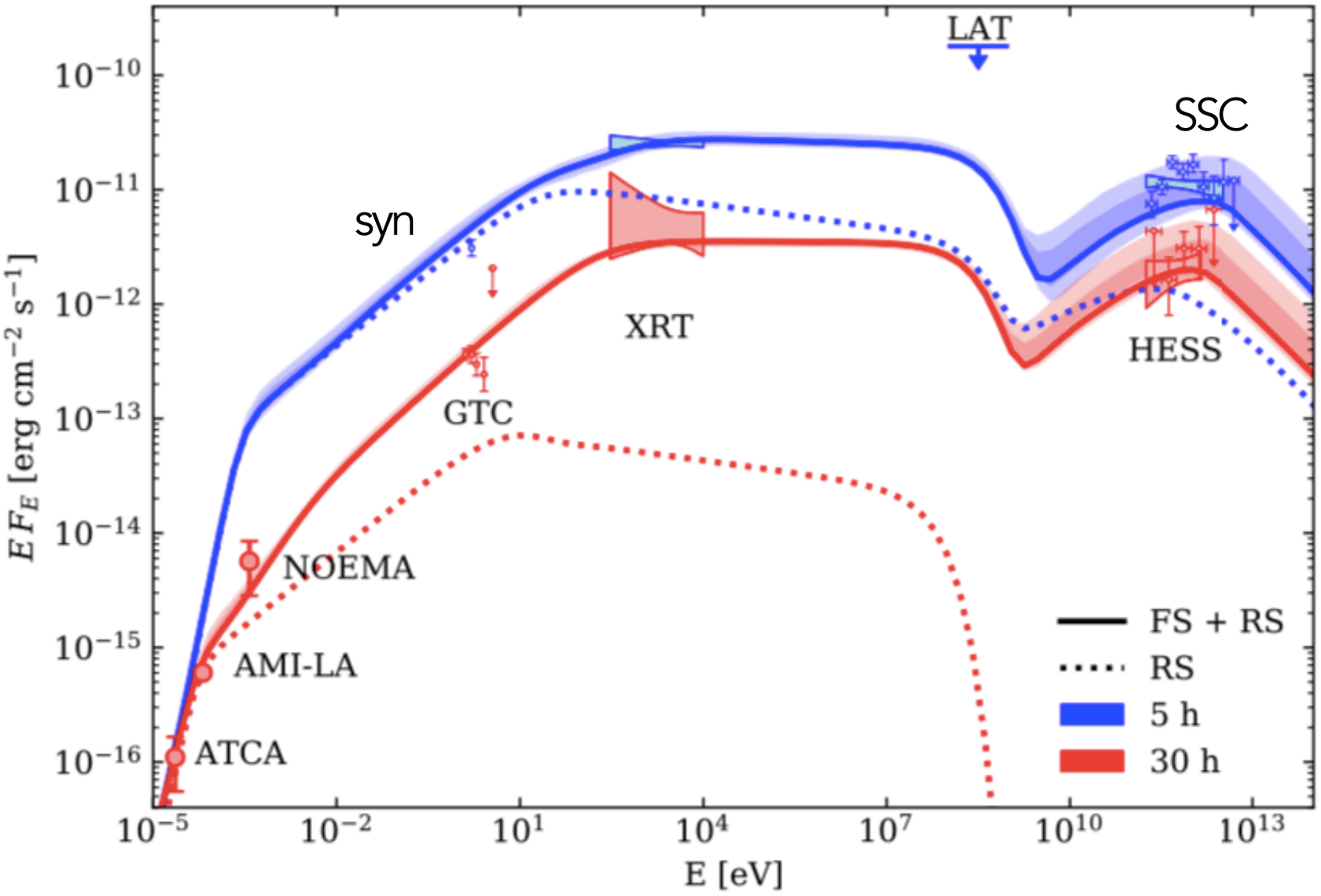
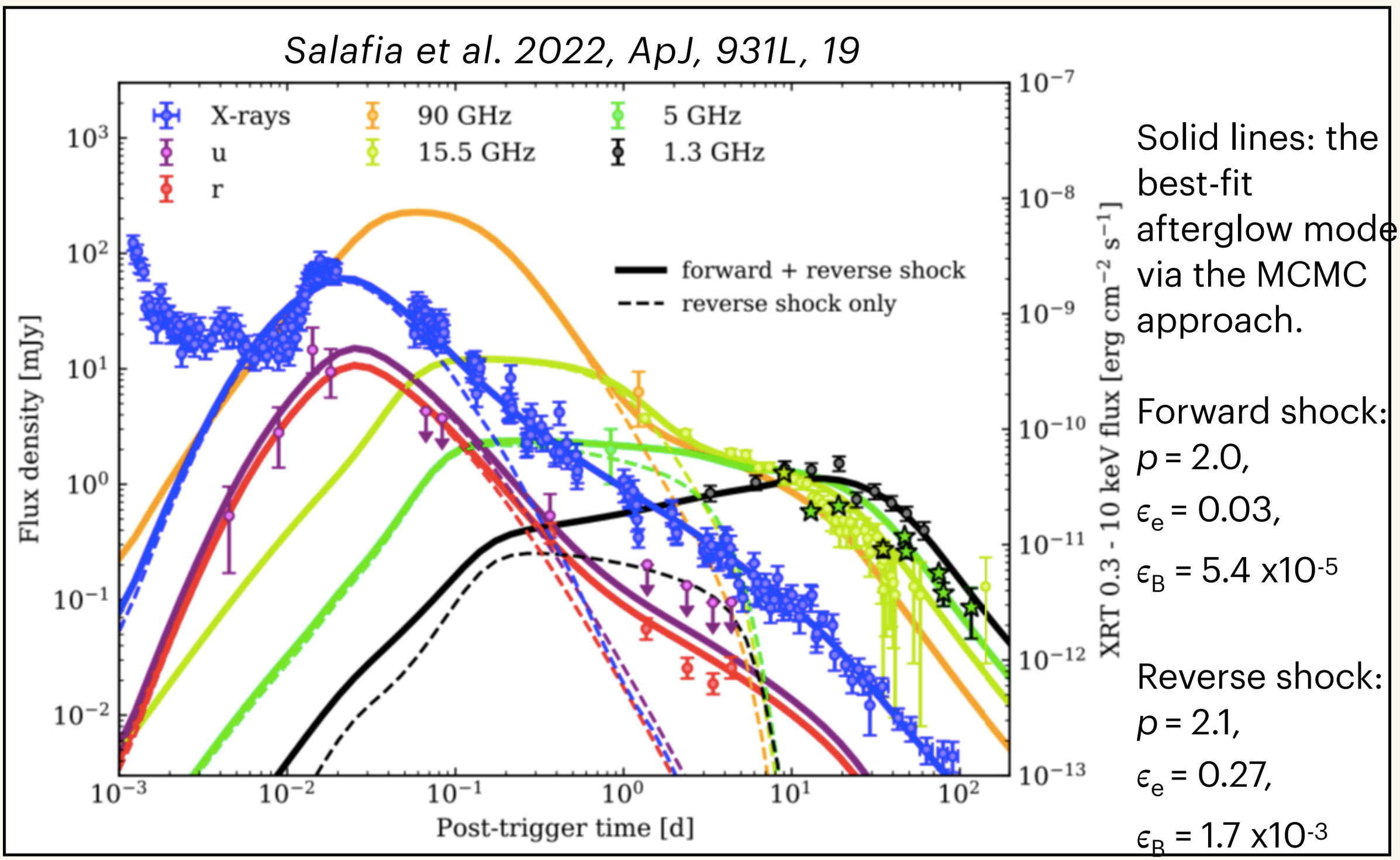


GRB 190829A: MODELING MW LIGHTCURVES

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



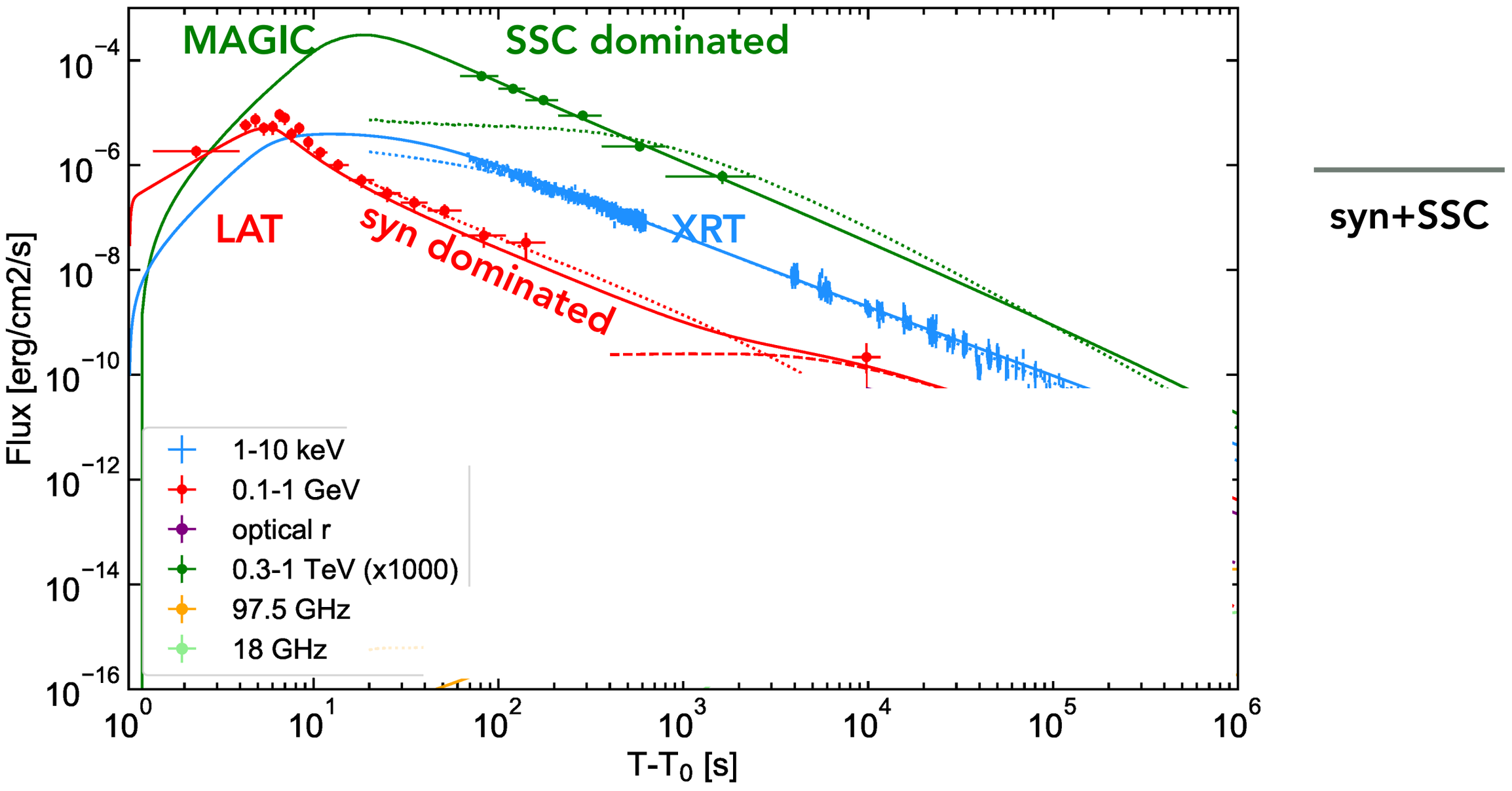
Solid lines: the best-fit afterglow model via the MCMC approach.

Forward shock:
$p = 2.0$,
$\epsilon_e = 0.03$,
$\epsilon_B = 5.4 \times 10^{-5}$

Reverse shock:
$p = 2.1$,
$\epsilon_e = 0.27$,
$\epsilon_B = 1.7 \times 10^{-3}$

MODELING WITH TWO COMPONENTS

MAGIC Collab, 2019, Nature, 575, 459



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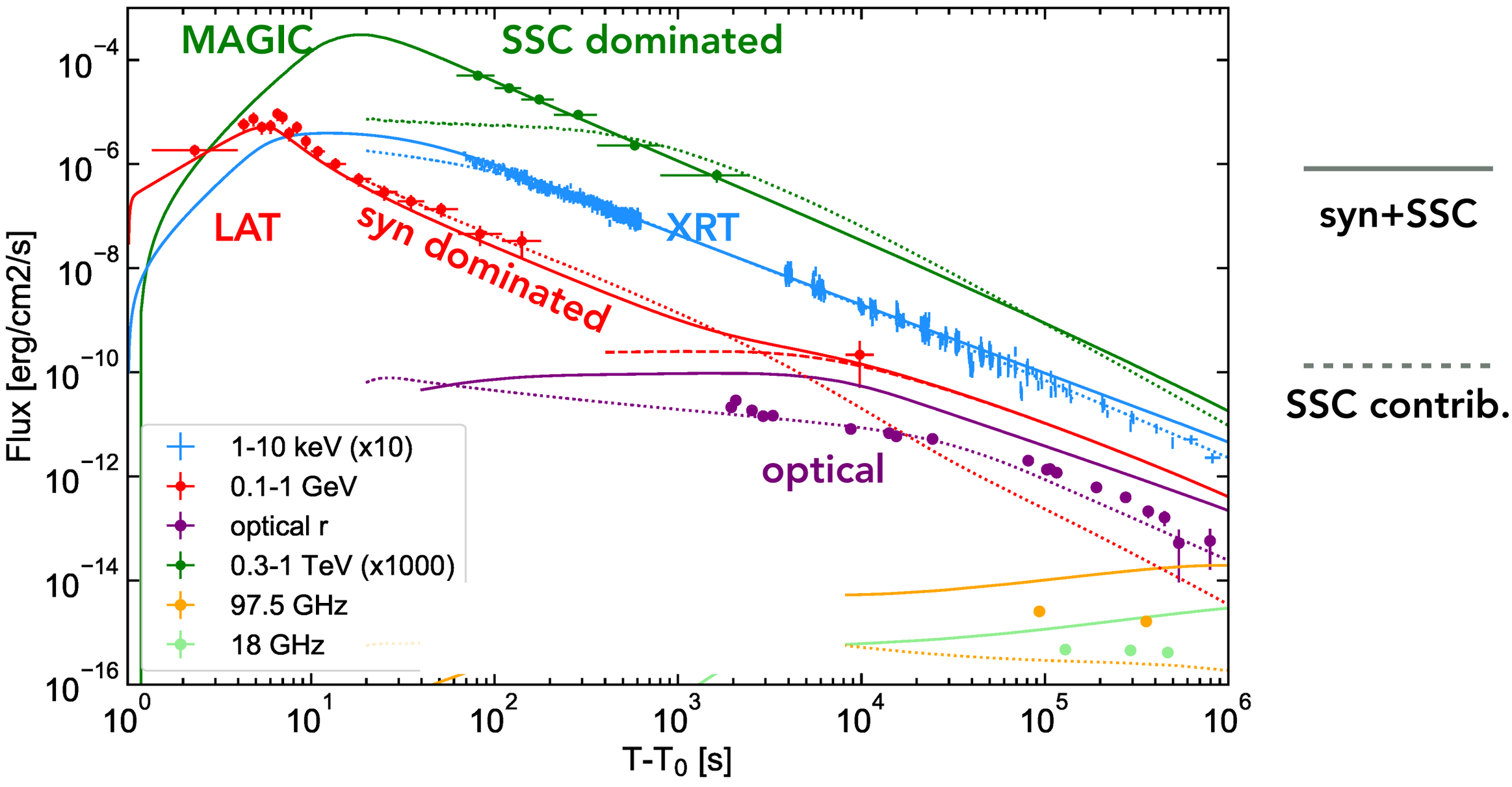
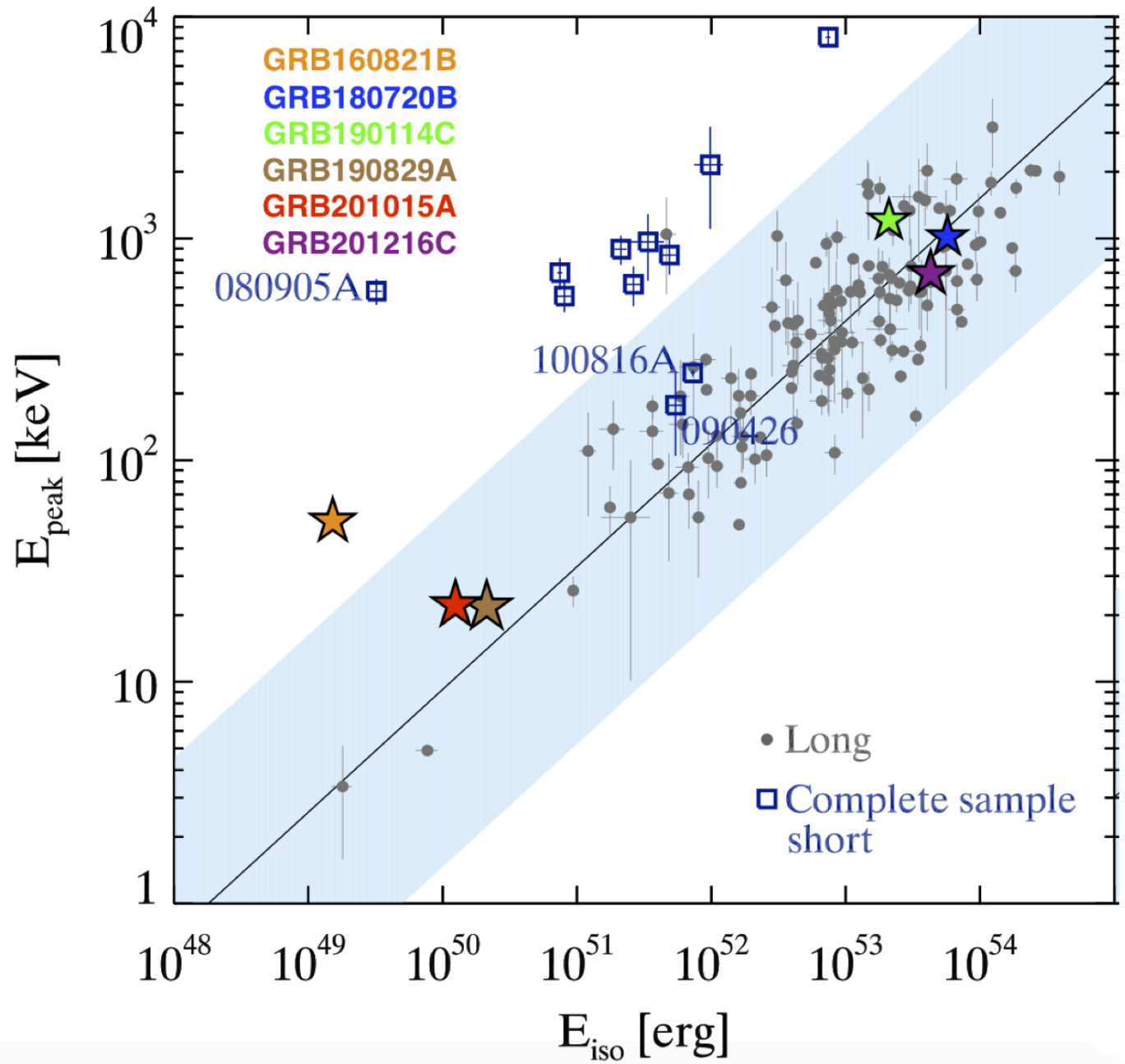


Amati correlation

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



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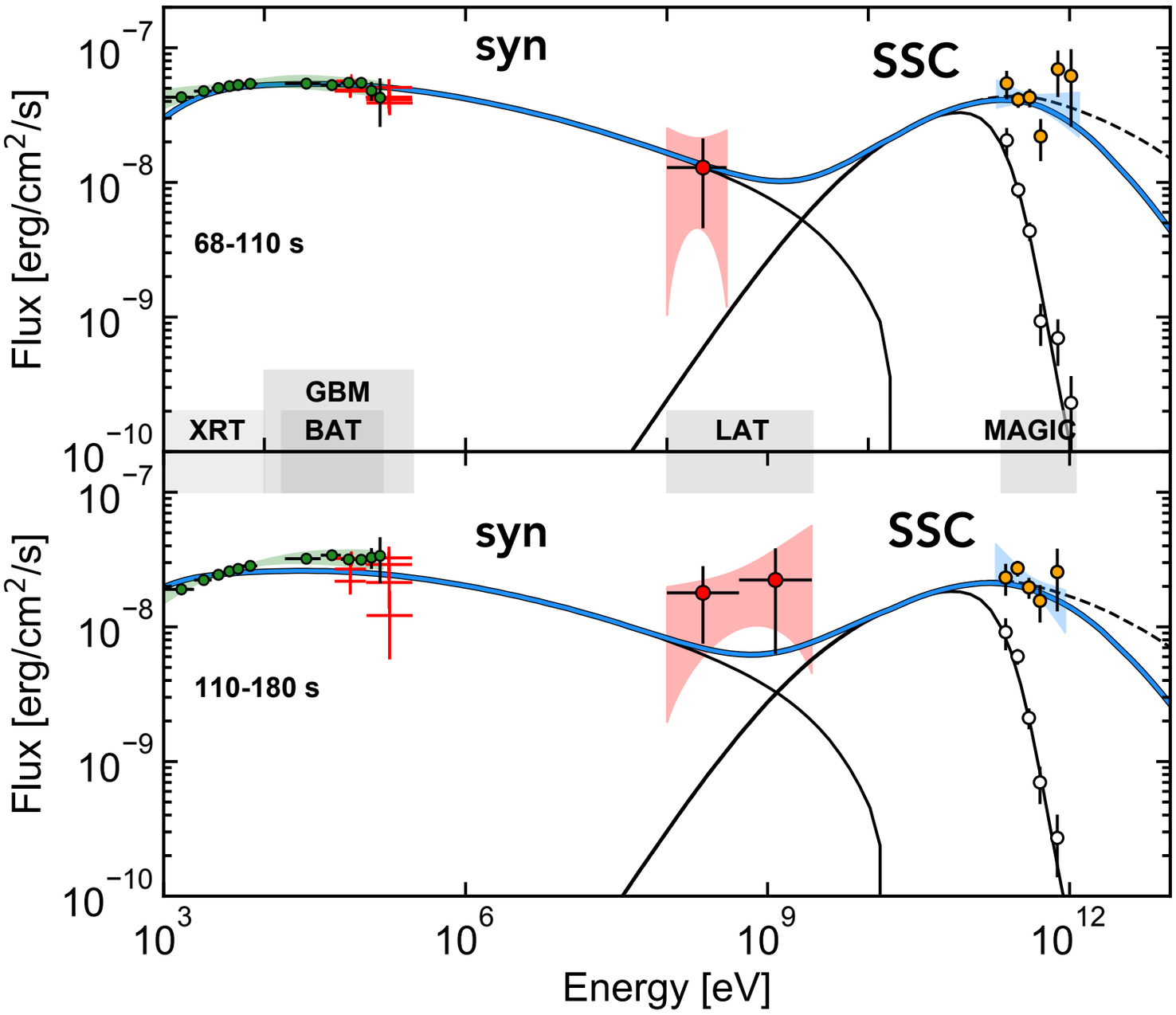


Best fit parameters

$E = 8 \times 10^{53}$ erg

$\Gamma = 700$

$s = 0$

$n_0 = 0.5$ cm^{-3}

$\varepsilon_e = 0.07$

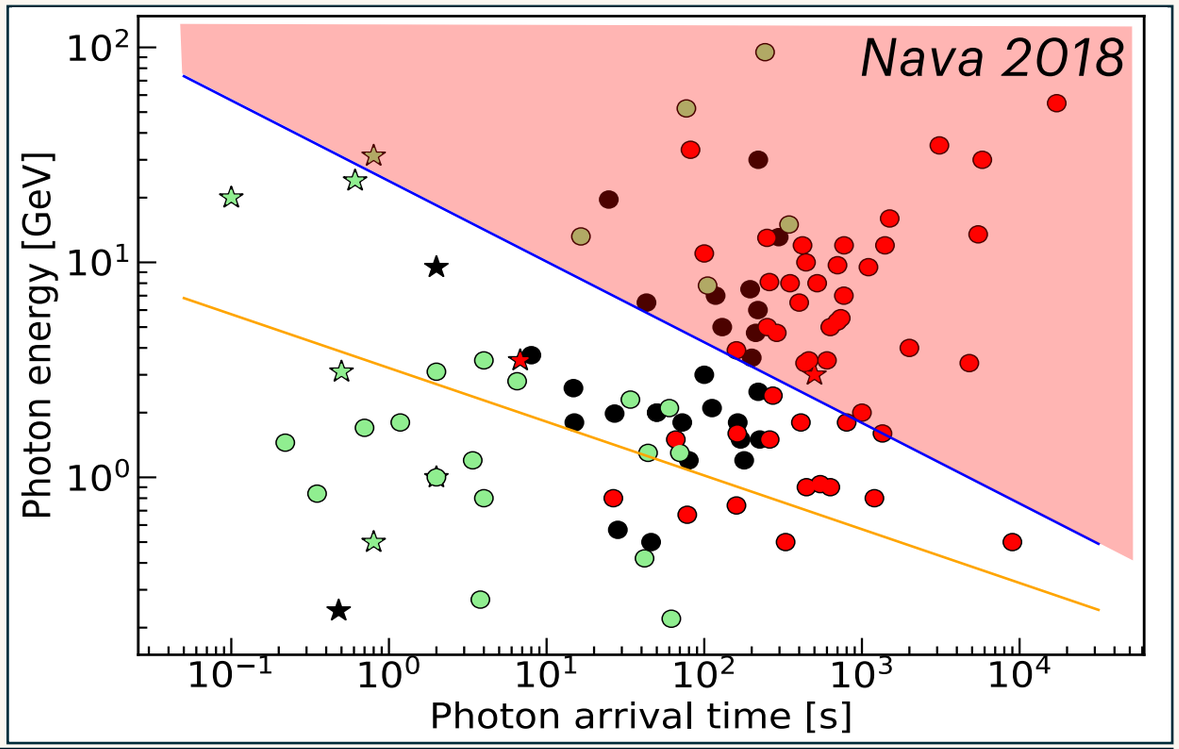
$\varepsilon_B = 8 \times 10^{-5}$

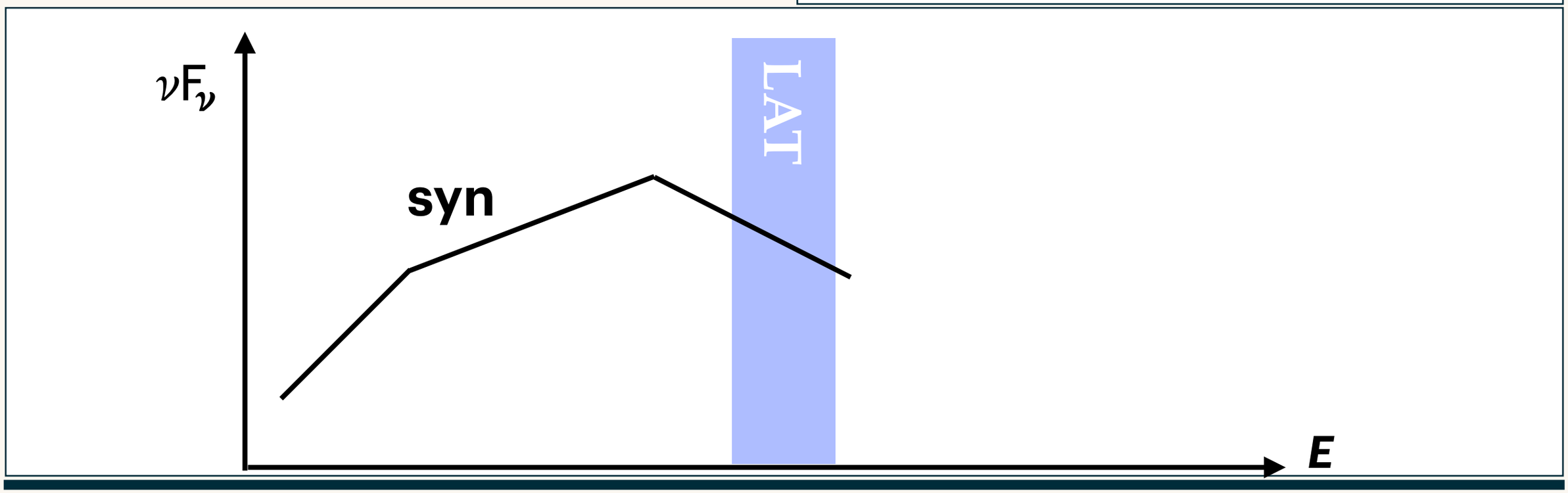
$p = 2.6$

Evidence for High-Energy additional spectral components from GeV observations

Afterglow emission

- Extra-component in spectra??
  (no clear evidence)
- Photons with *E>Emax,syn: revision of afterglow shock physics required (Kouveliotou et al 2013)? B-field decay (e.g., Kumar et al., 2012)?*





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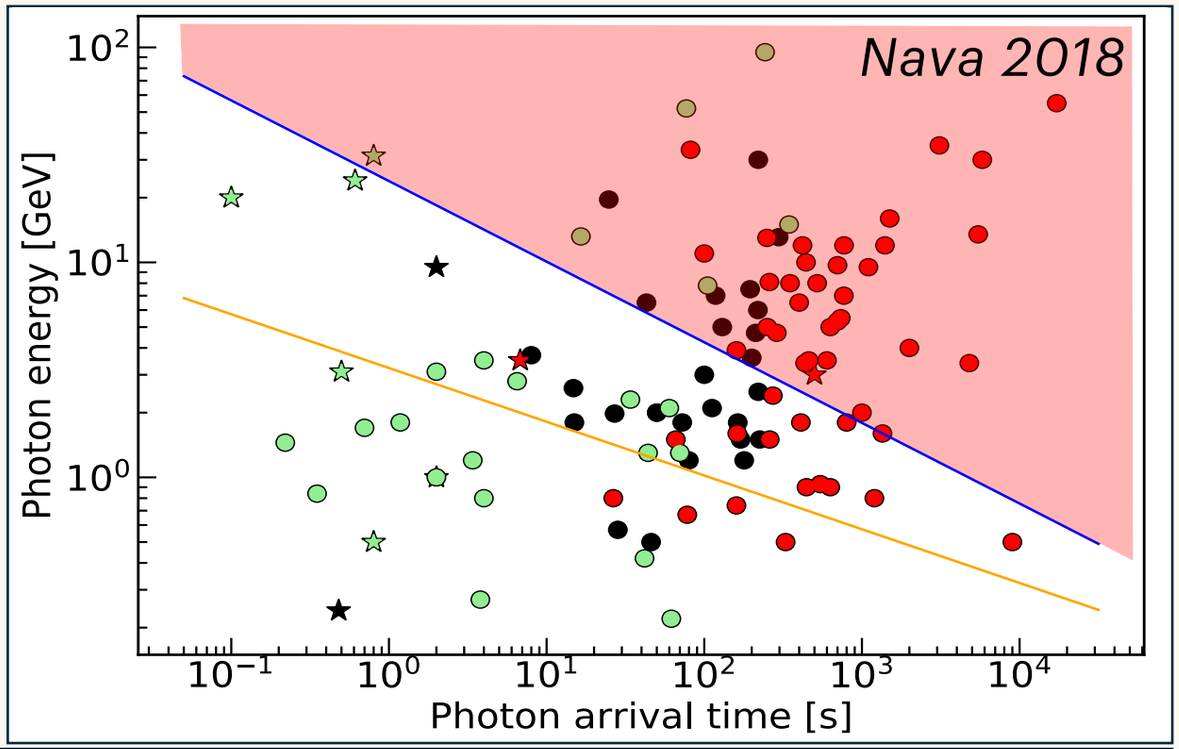

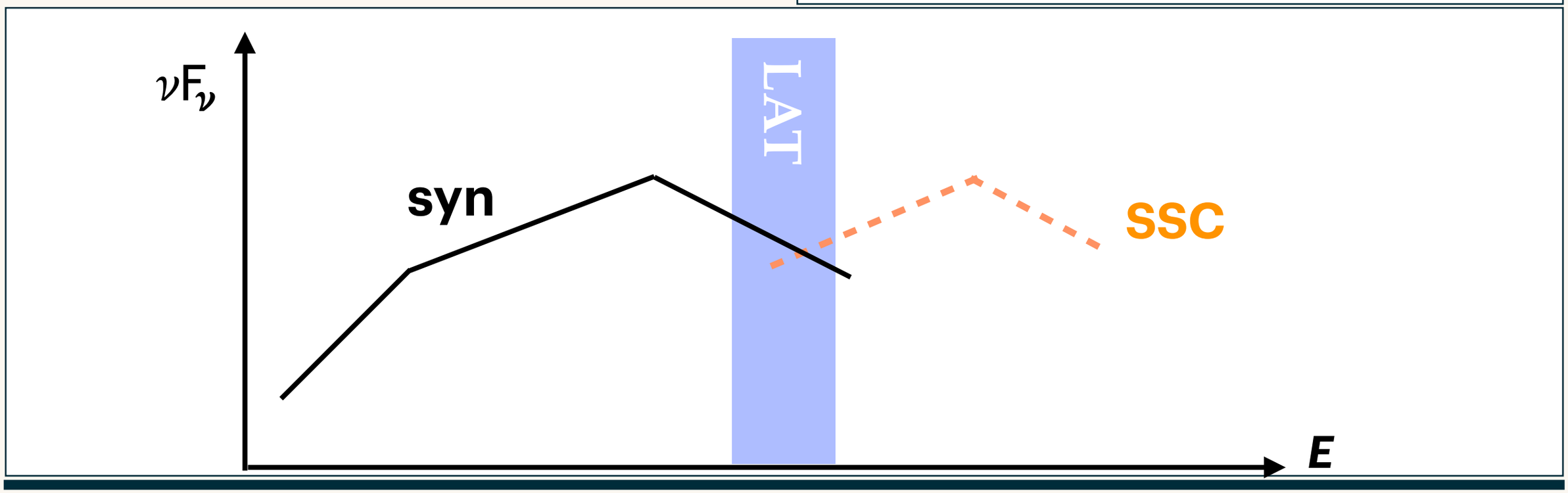

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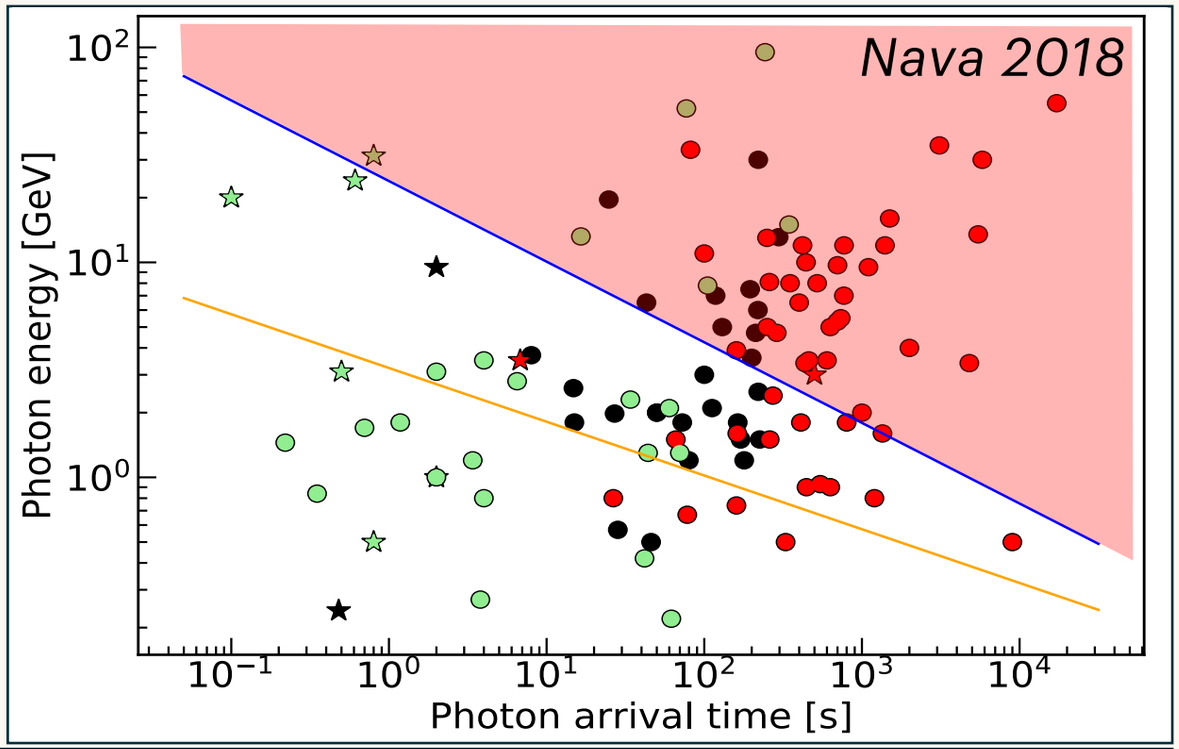

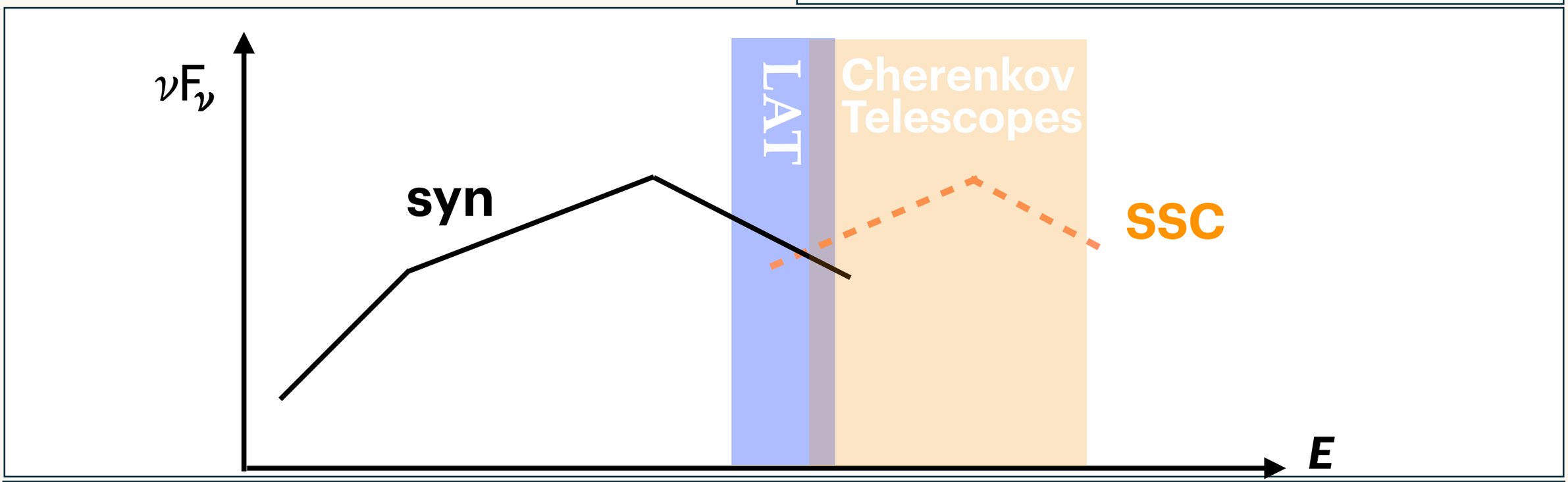

GRB 221009A

An intrinsically luminous GRB at z = 0.15

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, max photon energy 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
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