A PRELIMINARY POPULATION STUDY OF GAMMA RAY BURSTS DETECTED IN THE VERY HIGH ENERGY DOMAIN

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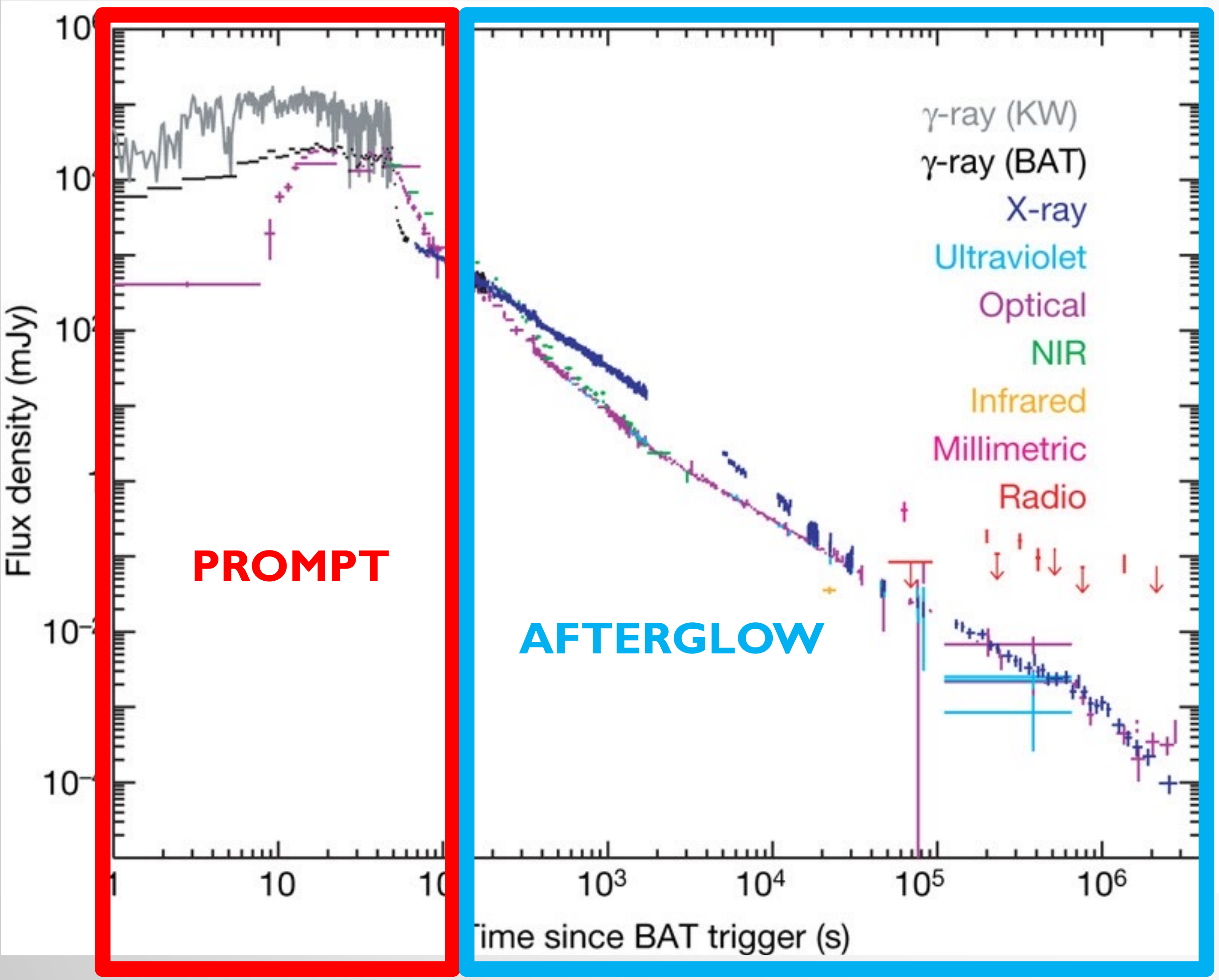
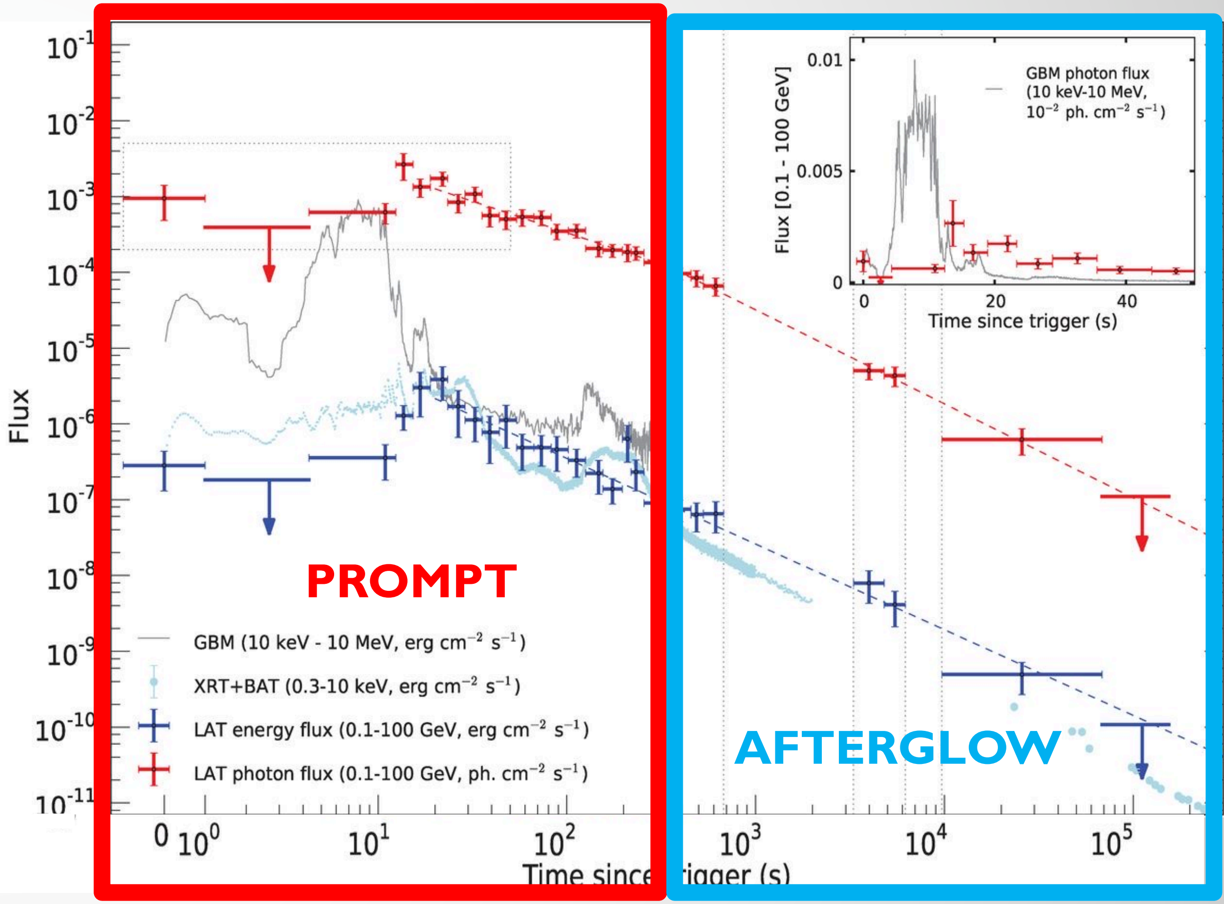
TeVPA 2022, 11/08/2022

Emission in Gamma-ray Bursts

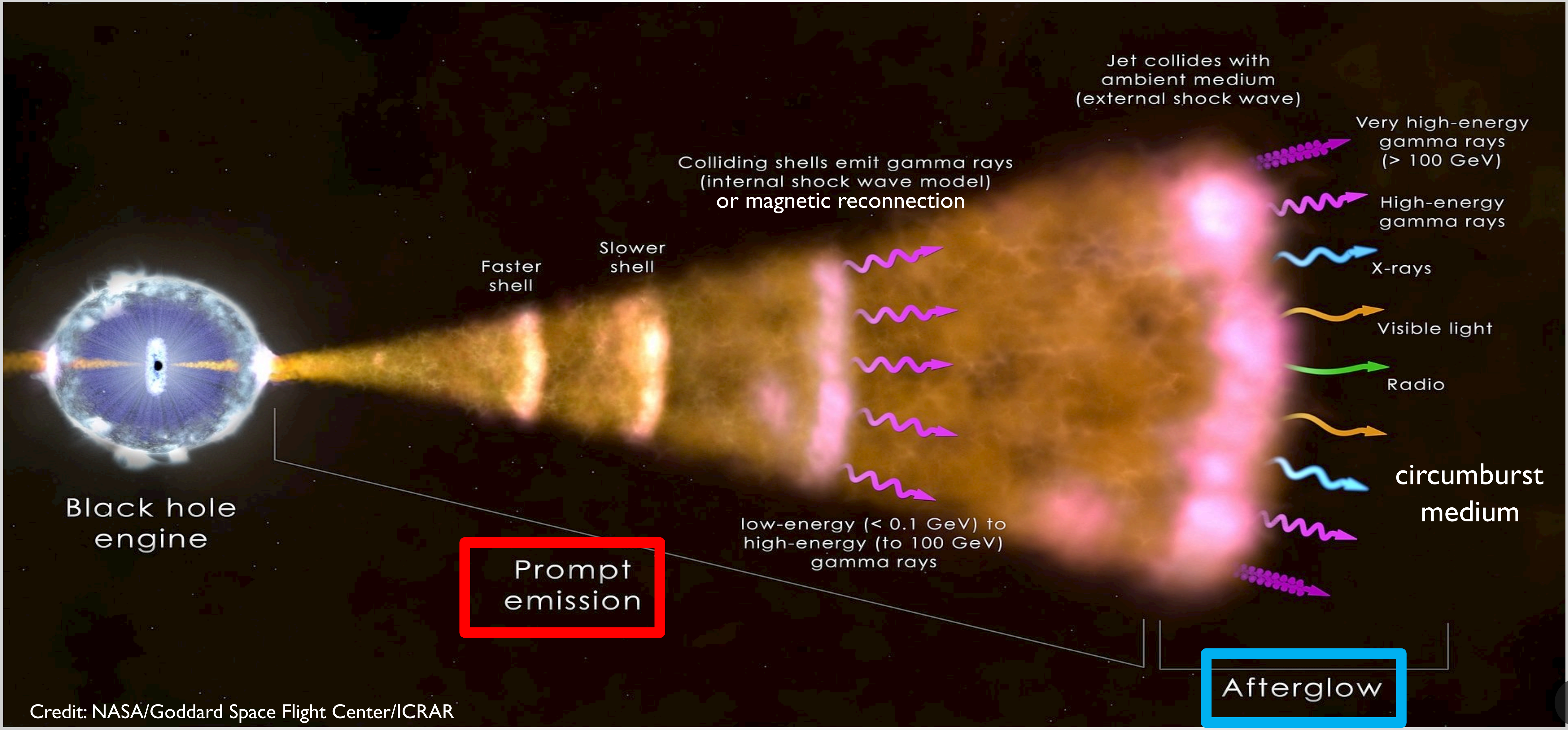


GRB080319B (Racusin et al., 2008)



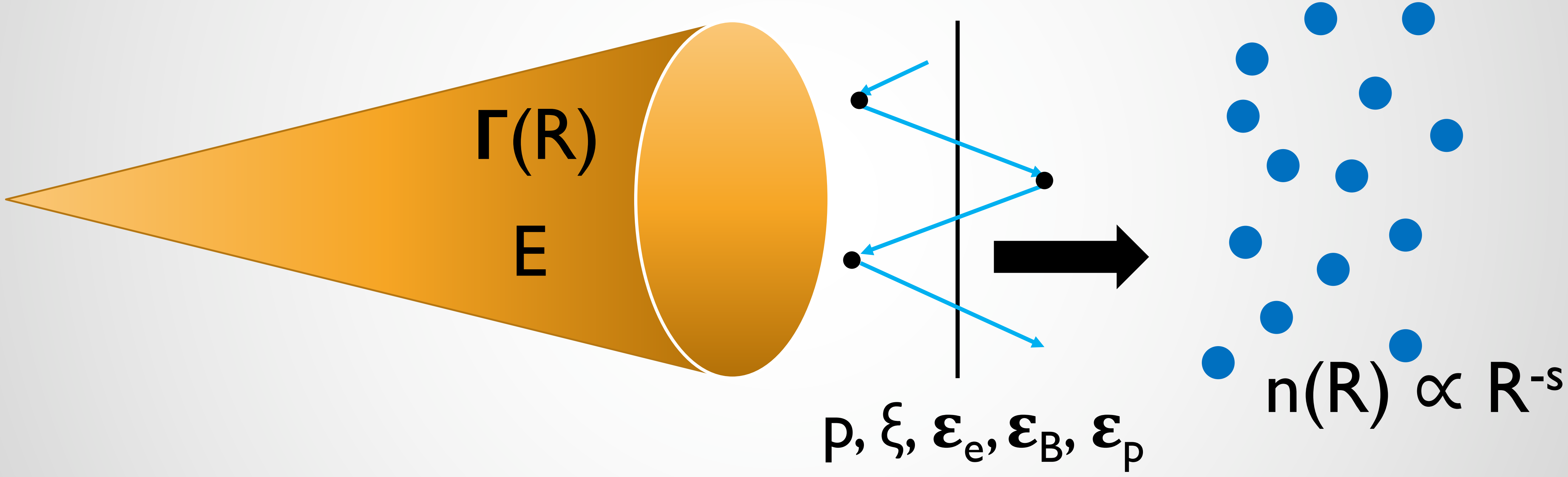
GRB130427A (Ackermann et al., 2013)

GRB Standard Model



Afterglow: the external forward shock scenario

Decelerating blastwave interacting with the circumburst external medium



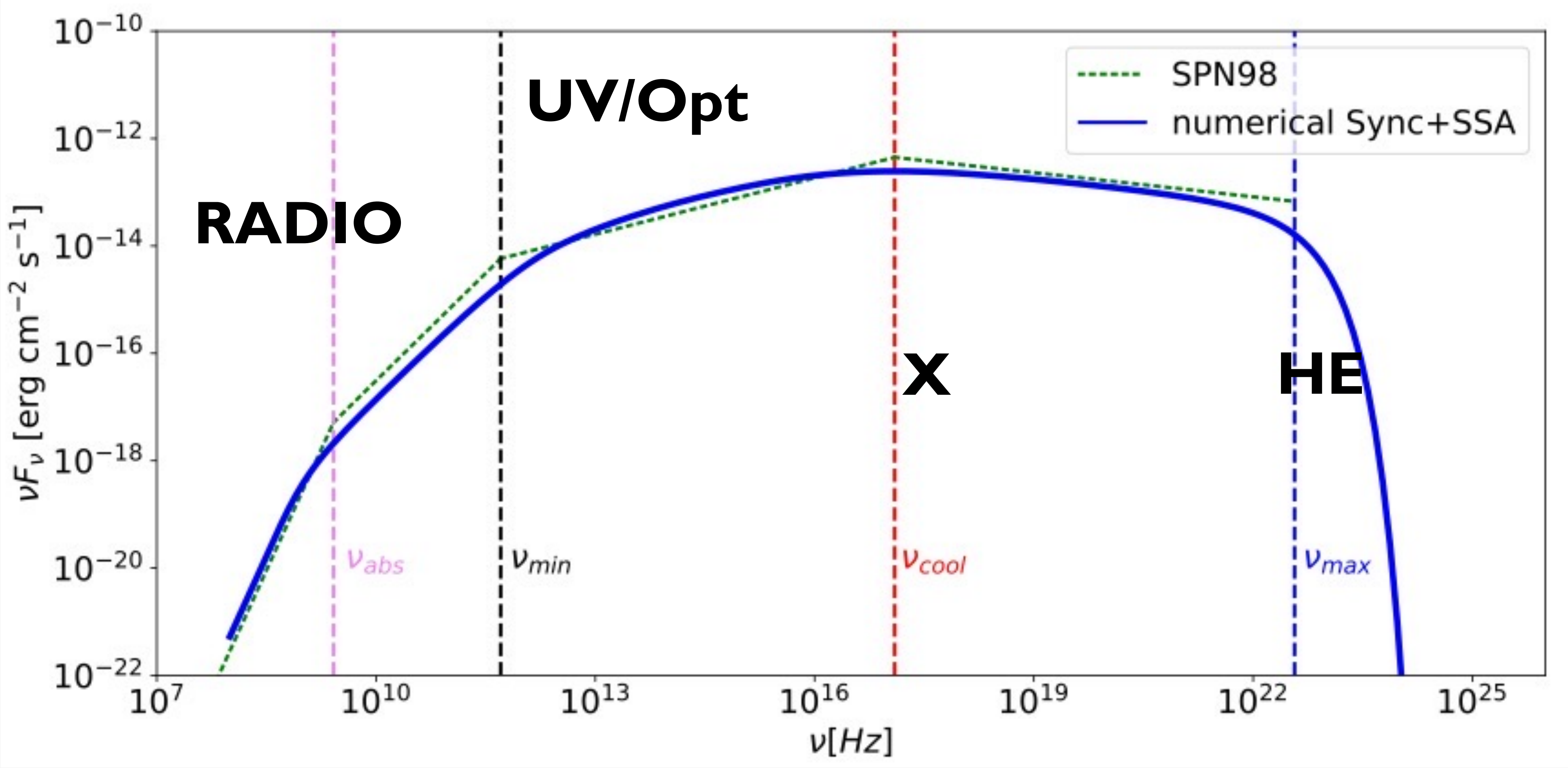
Jet dynamics

Relativistic shock acceleration

External circumburst medium

Numerical multi-wavelength afterglow modeling

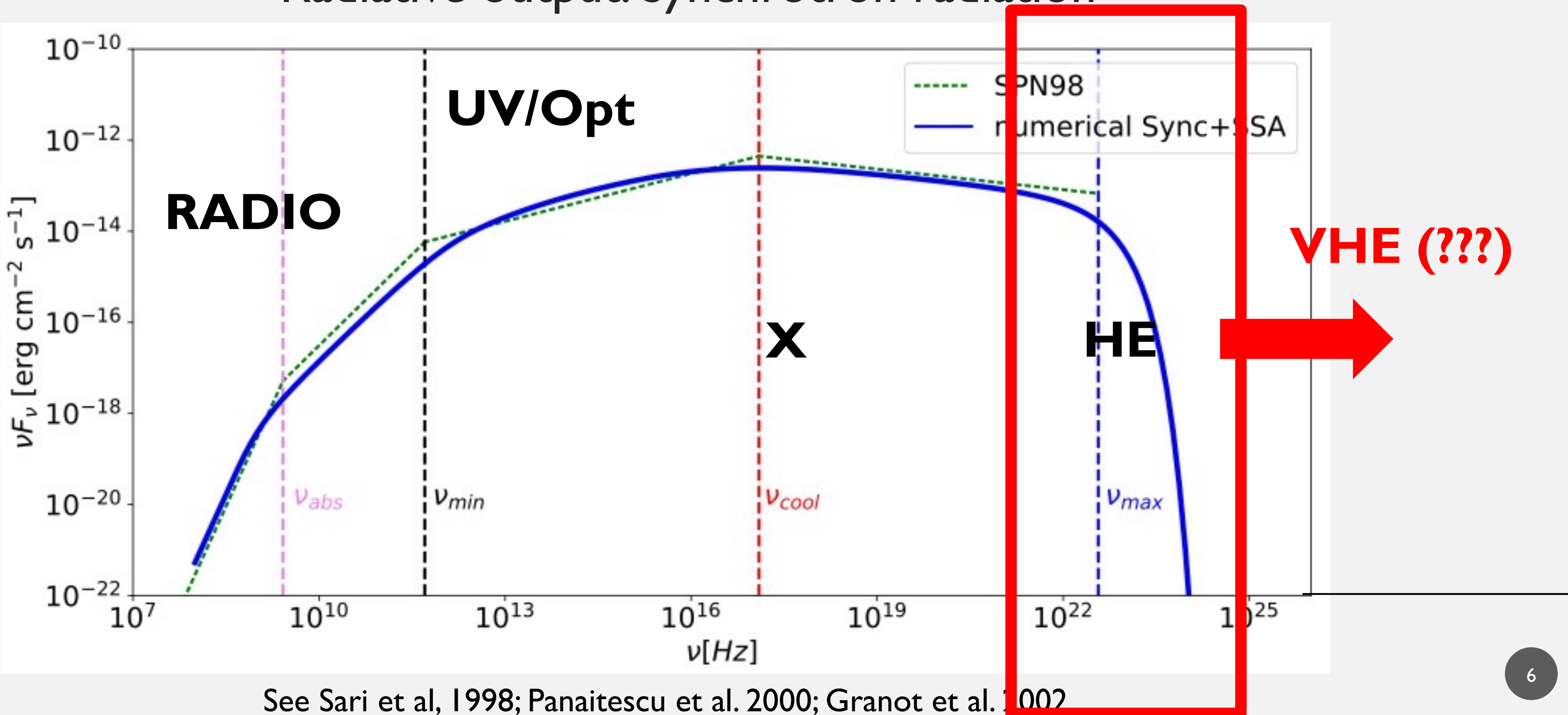
Radiative output: Synchrotron radiation



See Sari et al, 1998; Panaitescu et al. 2000; Granot et al. 2002

Numerical multi-wavelength afterglow modeling

Radiative output: Synchrotron radiation

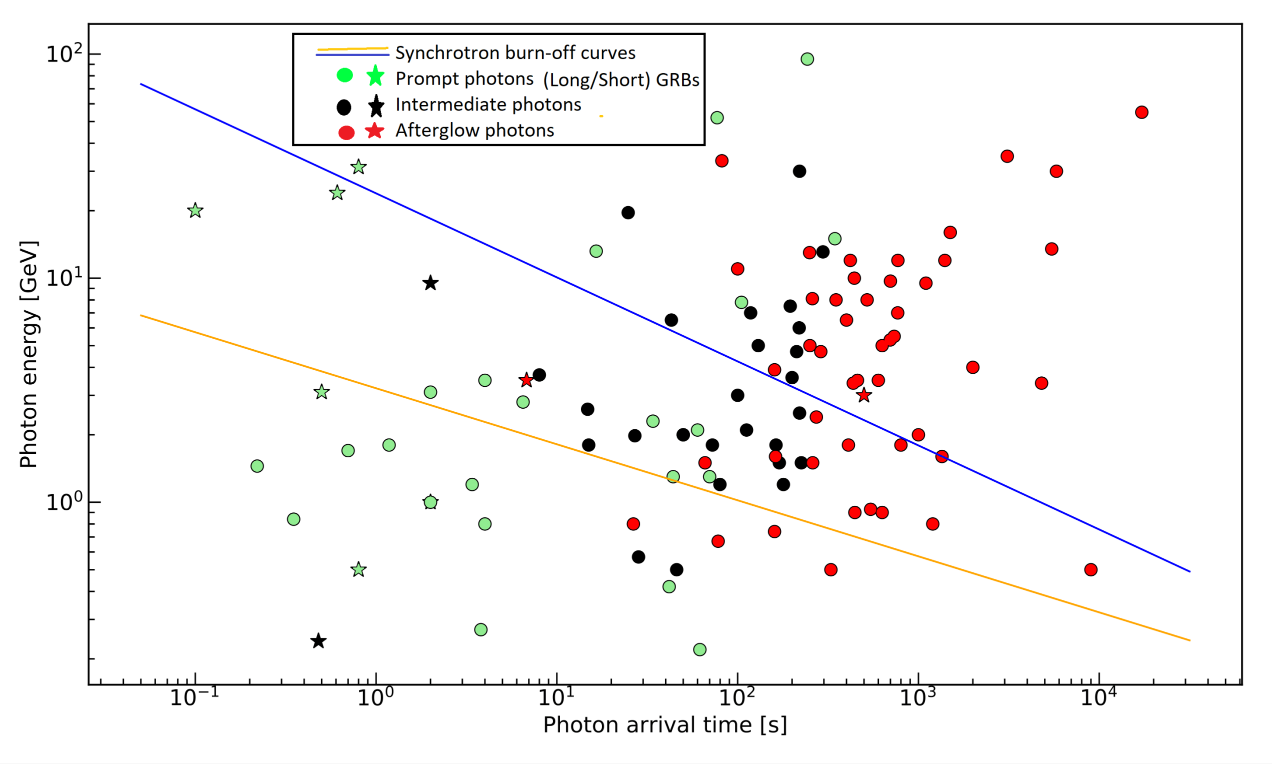


See Sari et al, 1998; Panaitescu et al. 2000; Granot et al. 2002

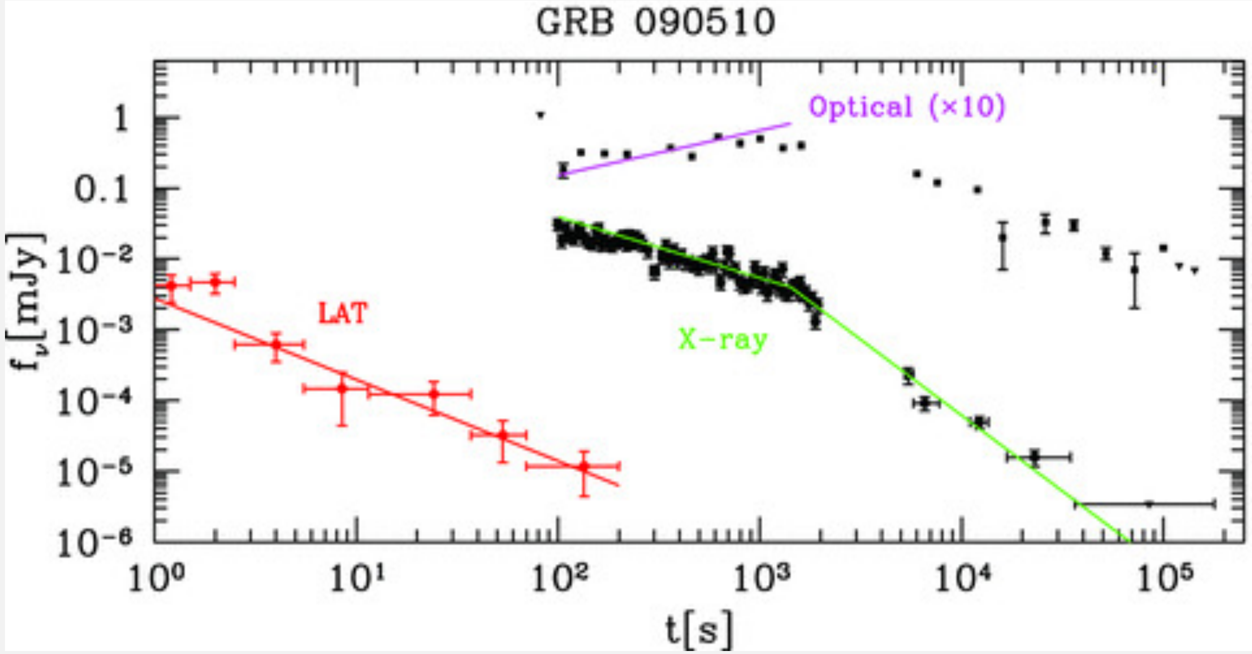
Open Issue: the HE and VHE radiation

HE emission

- Almost consistent with synchrotron radiation (synchrotron burnoff limit)
- No spectral cut-off identified (shock microphysics uncertaintes, non-uniform magnetic fields)



Nava, 2018



Kumar et al., 2010

Open Issue: the HE and VHE radiation

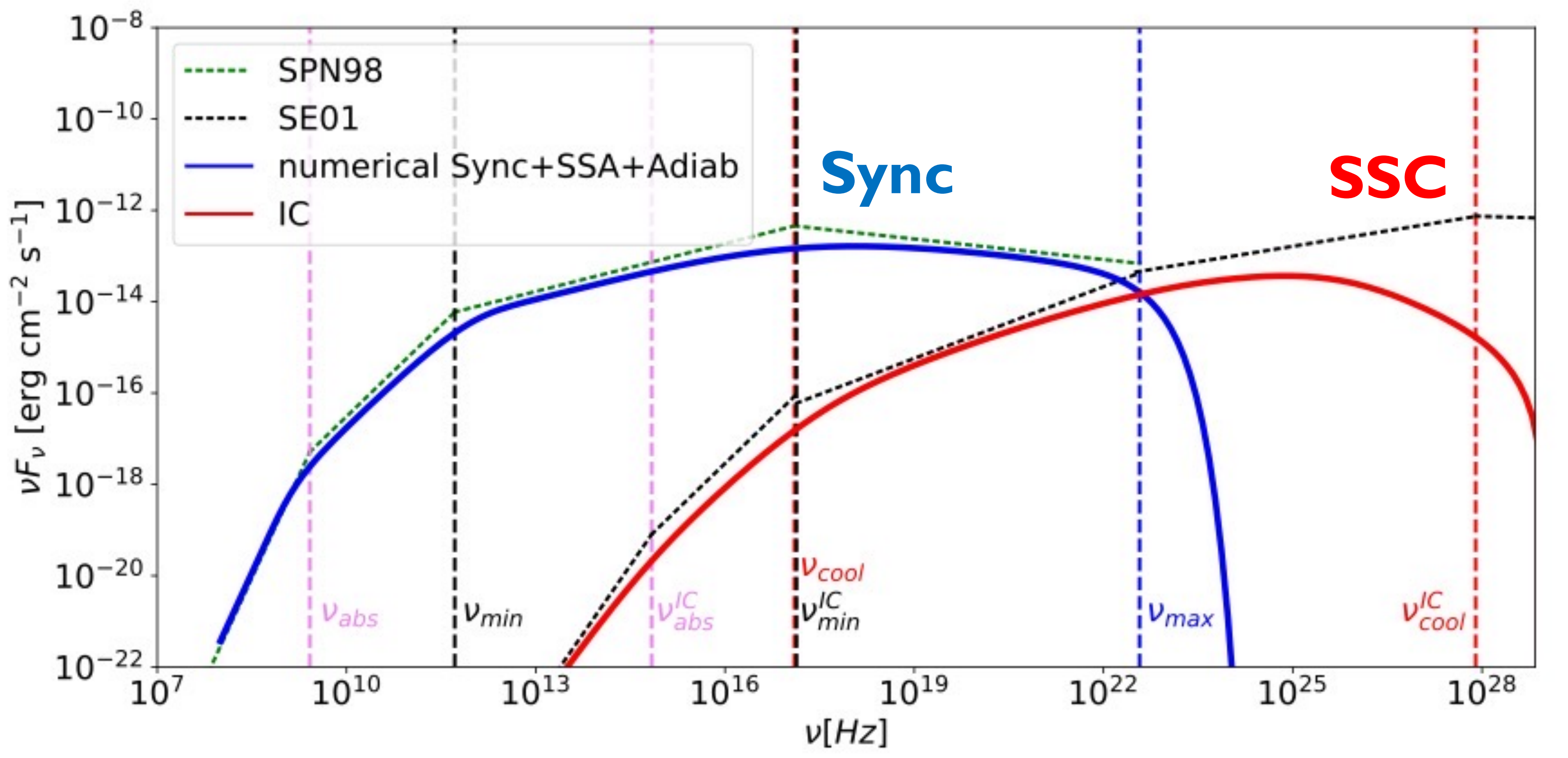
VHE emission

Possible radiation processes

- Synchrotron emission from e^- → Limited by burnoff limit, microphysics conditions, particle acceleration assumptions
- Synchrotron emission from p → Requires high radiative efficiency
- Synchrotron Self Compton (SSC) emission → Natural candidate (Sari et al., 2001; Nakar et al. 2009)

VHE emission

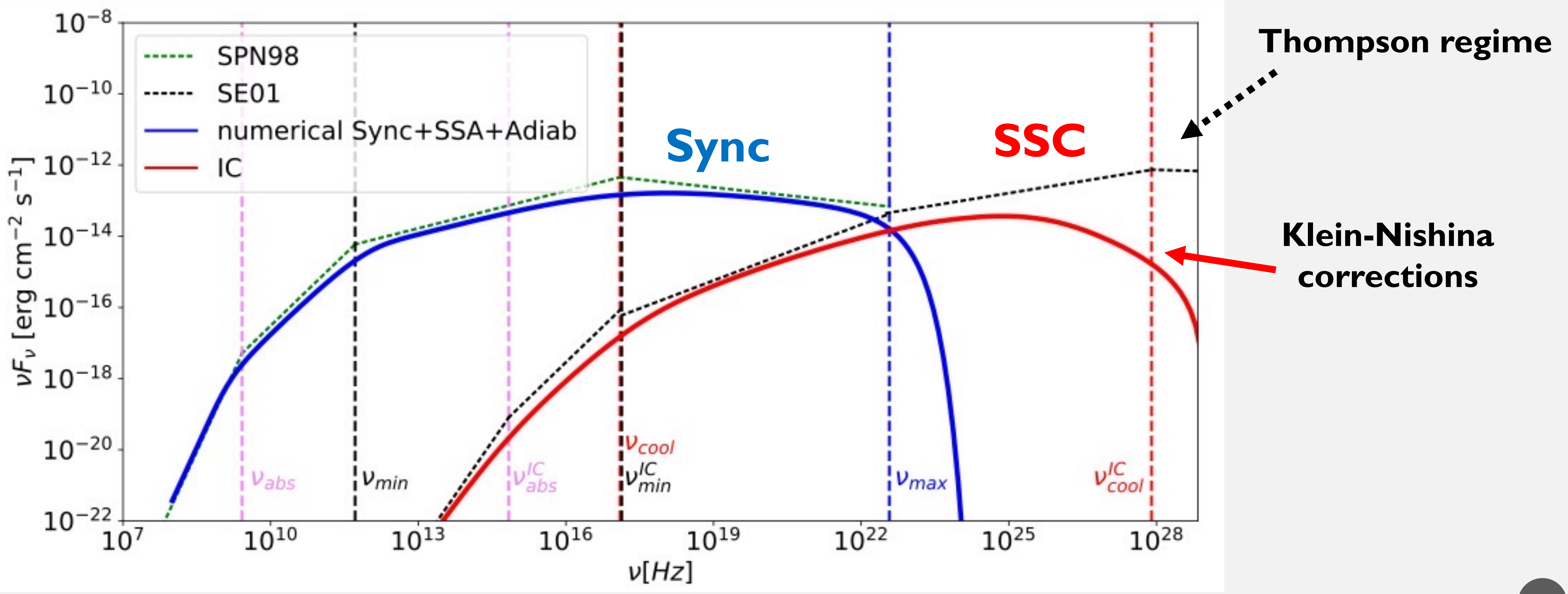
VHE emission



Miceli & Nava, 2022

VHE emission: KN corrections

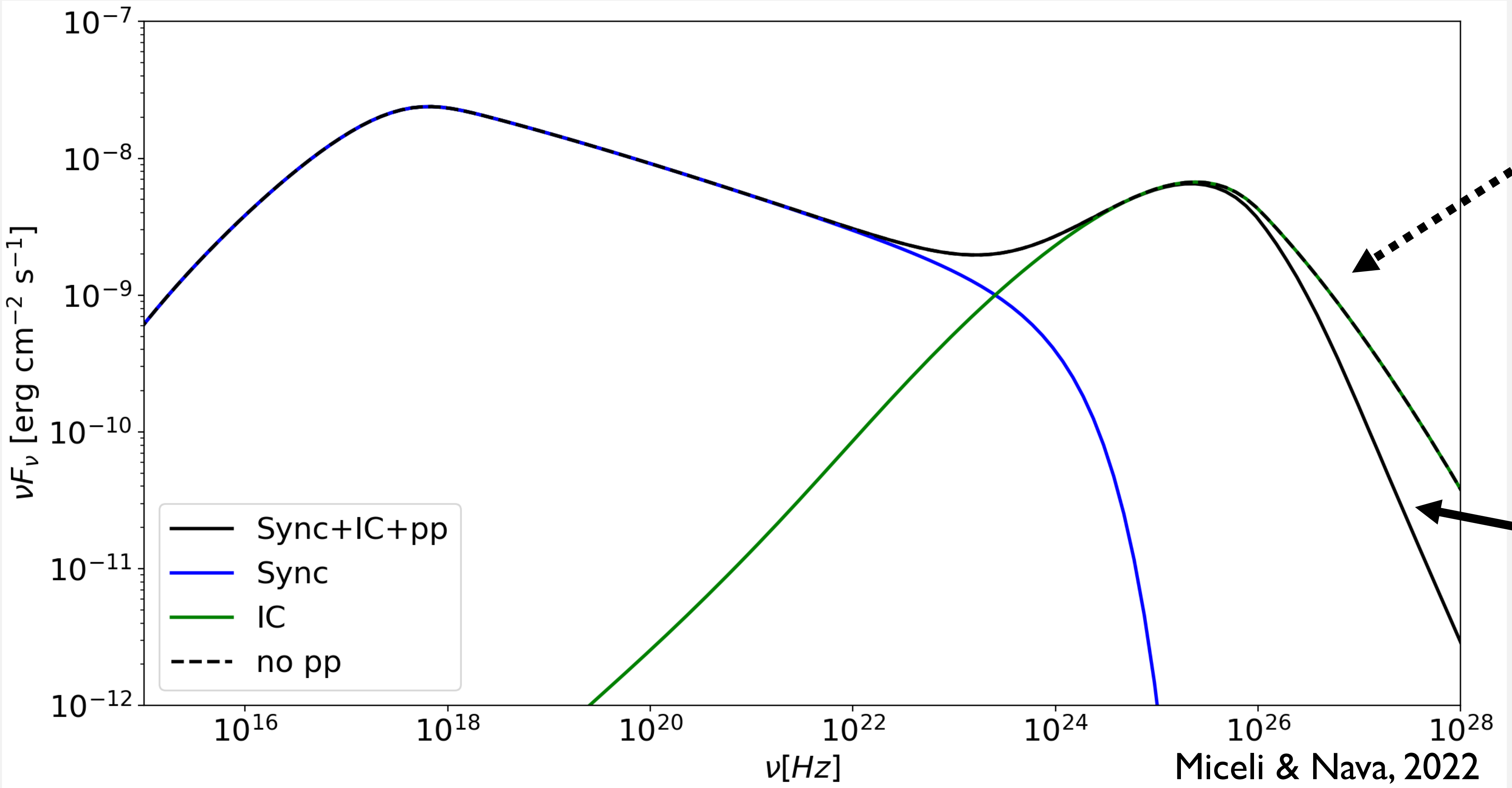
Shaping the VHE spectrum



Miceli & Nava, 2022

VHE emission: ɣɣ absorption

Shaping the VHE spectrum



No ɣɣ absorption

ɣɣ absorption included

VHE emission

Afterglow open issues

- Flares, plateaus not included in the external fwd shock scenario
- GRB environmental conditions (external medium profile: ISM? wind-like?)
- Shock microphysical parameters (ξ, ε_e, ε_B) unconstrained/time-dependent
- Absence of synchrotron spectral cutoff
- Prompt emission efficiency

VHE detection can provide renovate and boost afterglow studies

Population of GRBs at VHE

	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)

Miceli & Nava, 2022

Population of GRBs at VHE

What we have learned so far

- IACT Capabilities
- Redshift impact
- Energetics
- X-ray similarities and TeV modeling

Population of GRBs at VHE

IACT Capabilities

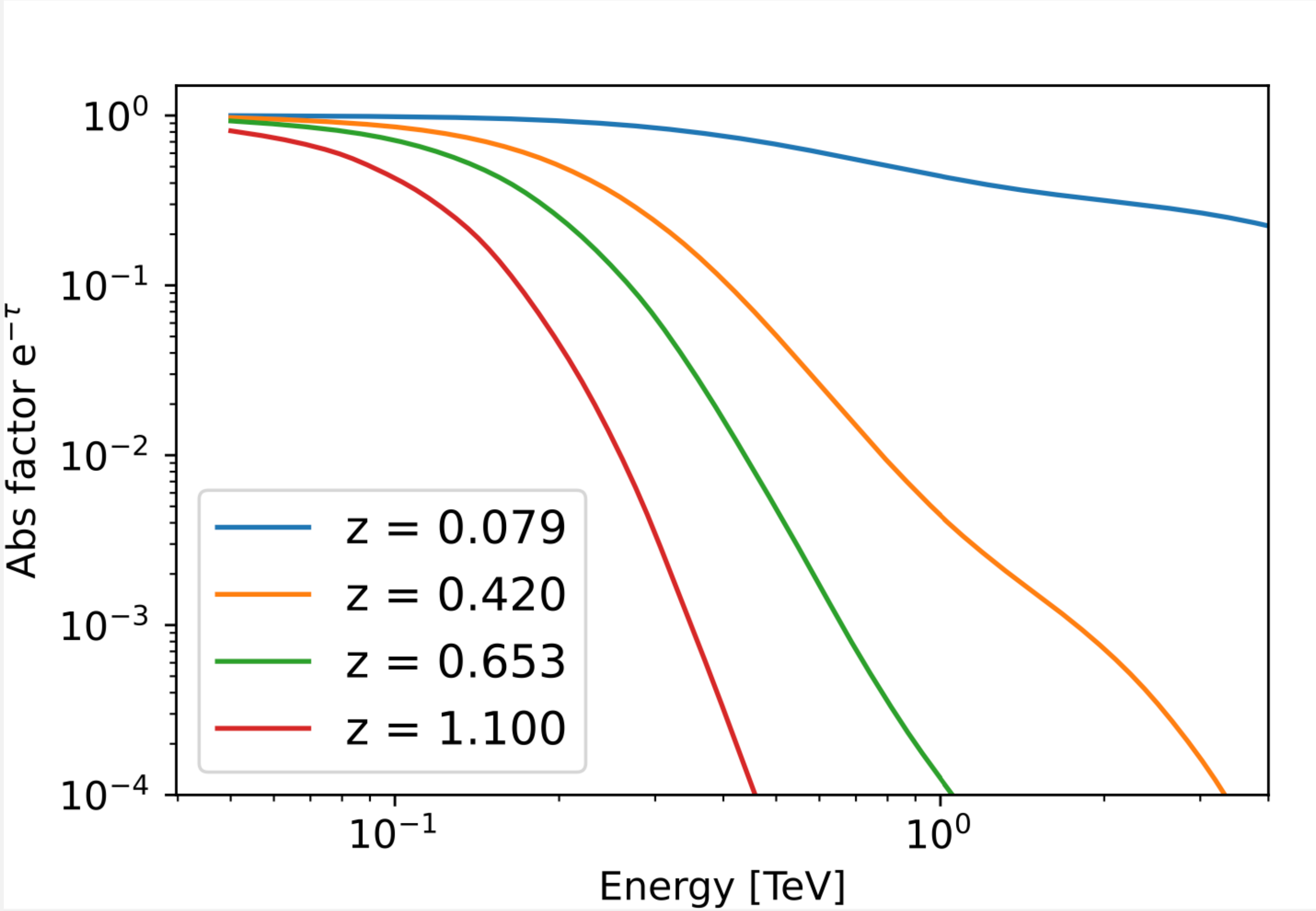
"Mandatory" requirements:

- low zenith angles
- dark nights
- small delays
- low z
- highly energetic events

GRB190114C: zenith >55°, Moon conditions
GRB160821B: Moon conditions
GRB180720B, GRB190829A: T_{delay} ~ hrs/days
GRB201216C: z = 1.1
GRB190829A, GRB201015A, GRB160821B: $E_{\gamma,iso} \sim 10^{49} - 10^{50}$ erg

Population of GRBs at VHE

Redshift



Dominguez et al., 2011
(similar for other EBL models)

z = 0.4

- F_{att}~ 50% at 0.2 TeV
- F_{att}~ 99.5% at 1 TeV

$z \lesssim 0.1 - 0.2$

- F_{att} relevant above 300 GeV
- F_{att}~ 90% at 1 TeV

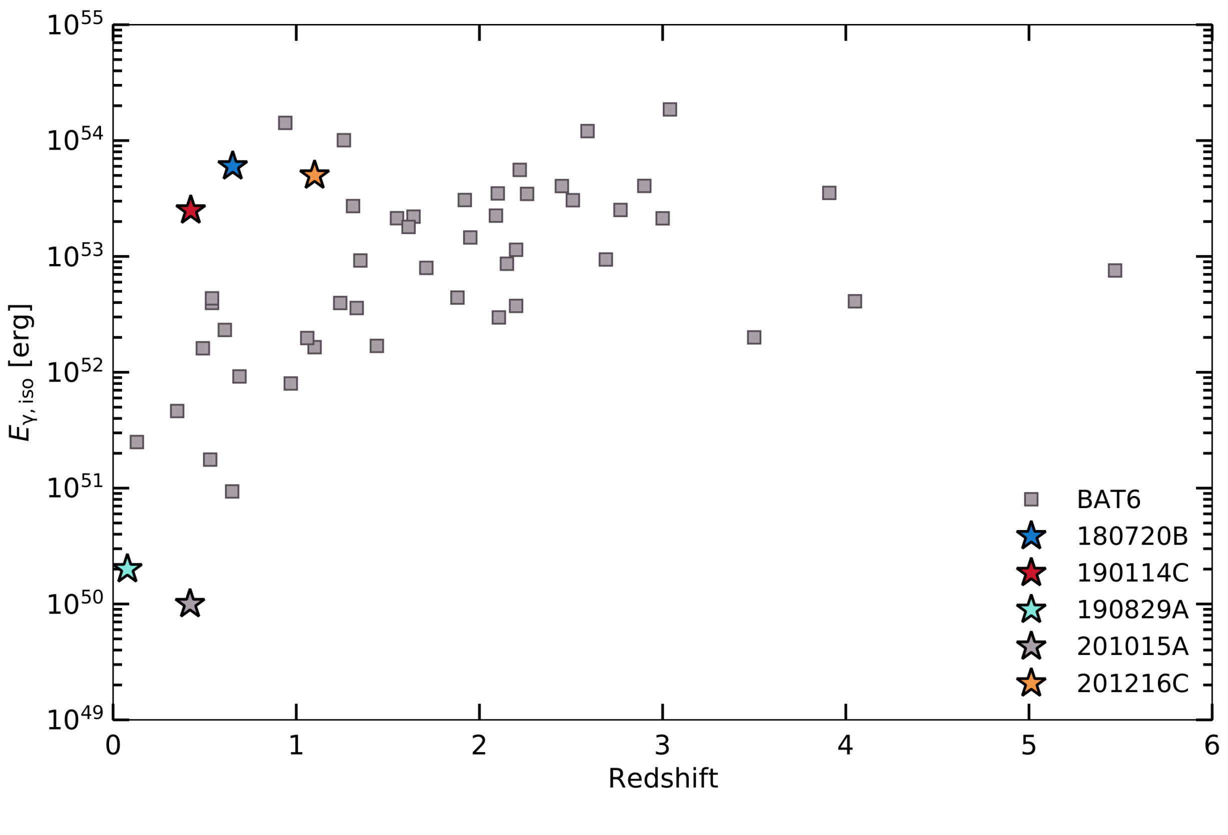
z = 1.1

- F_{att}~ 95% at 0.2 TeV

Population of GRBs at VHE

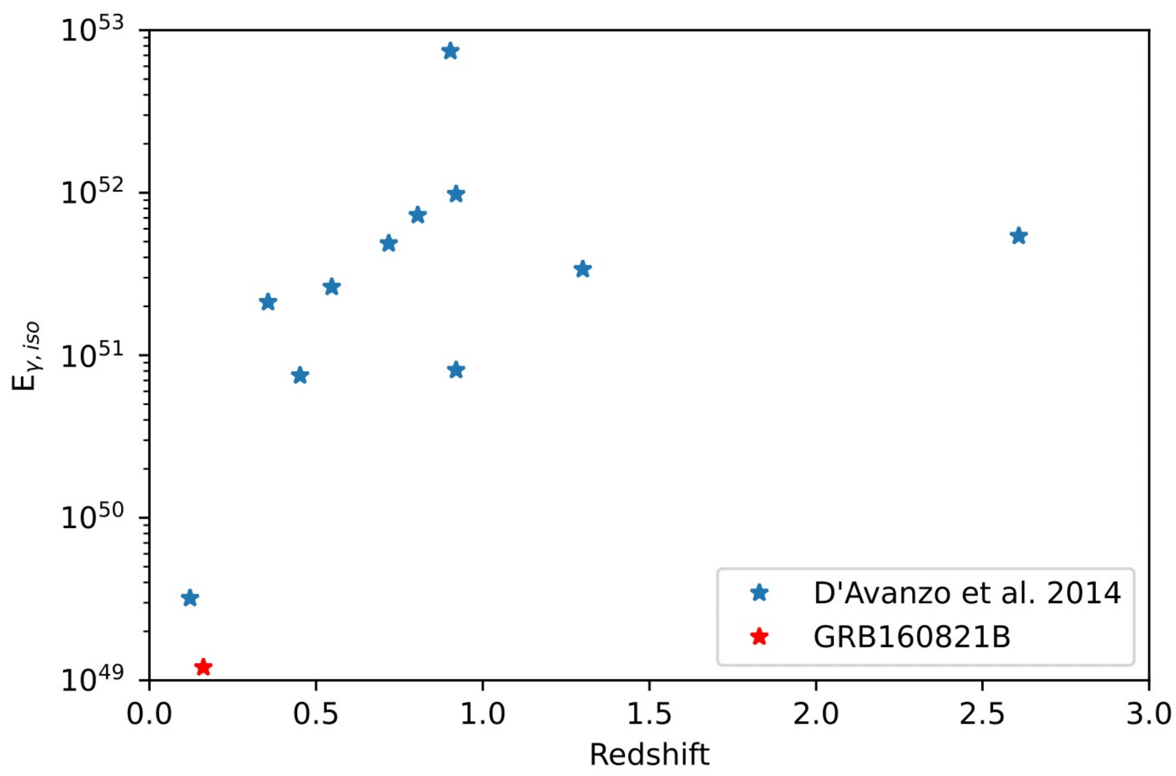
Energetics

long GRBs



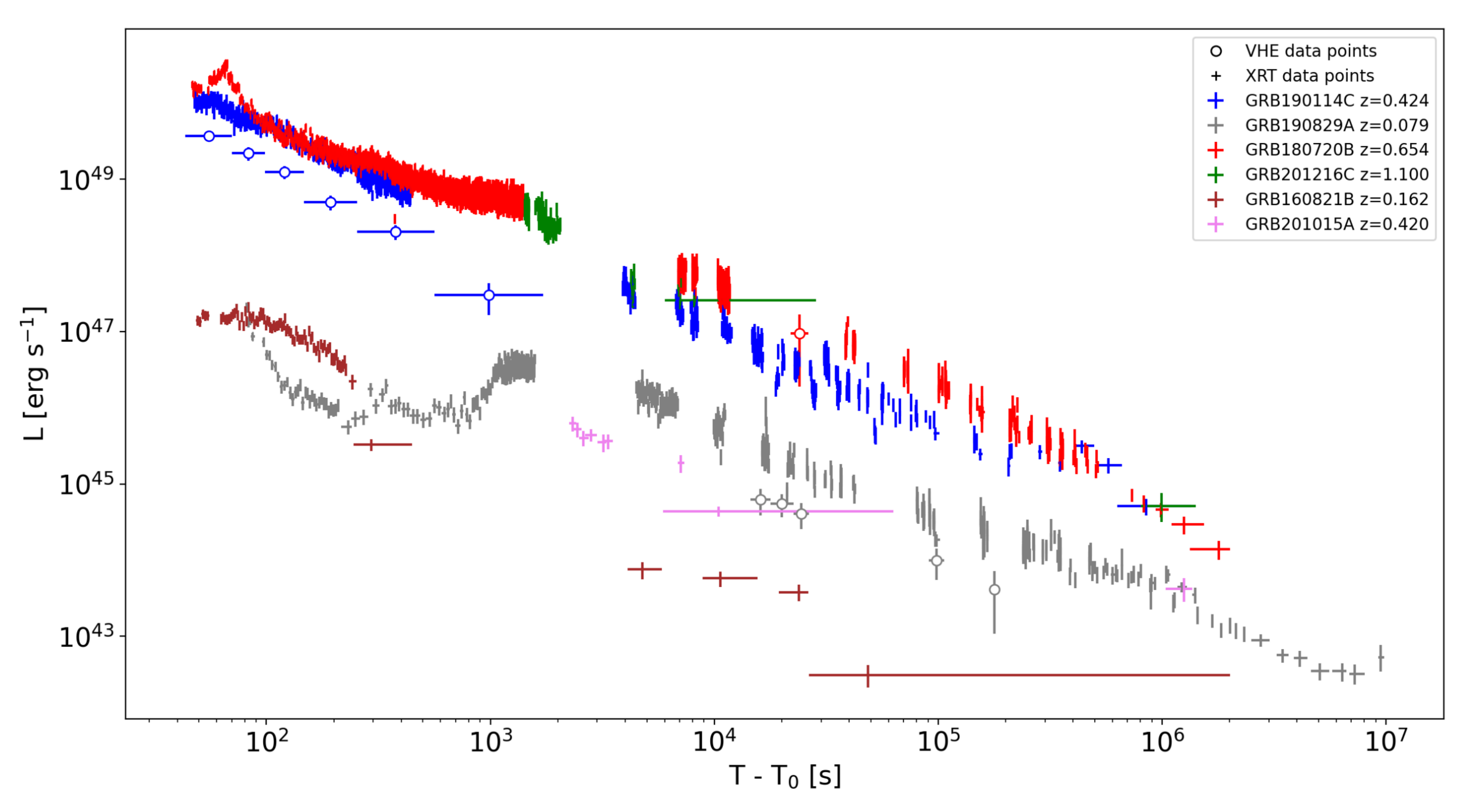
Nava, 2021

short GRBs



X-ray similarities

- $L_X \propto E_{\gamma,iso}$
- L_{VHE} ~15-60% L_X

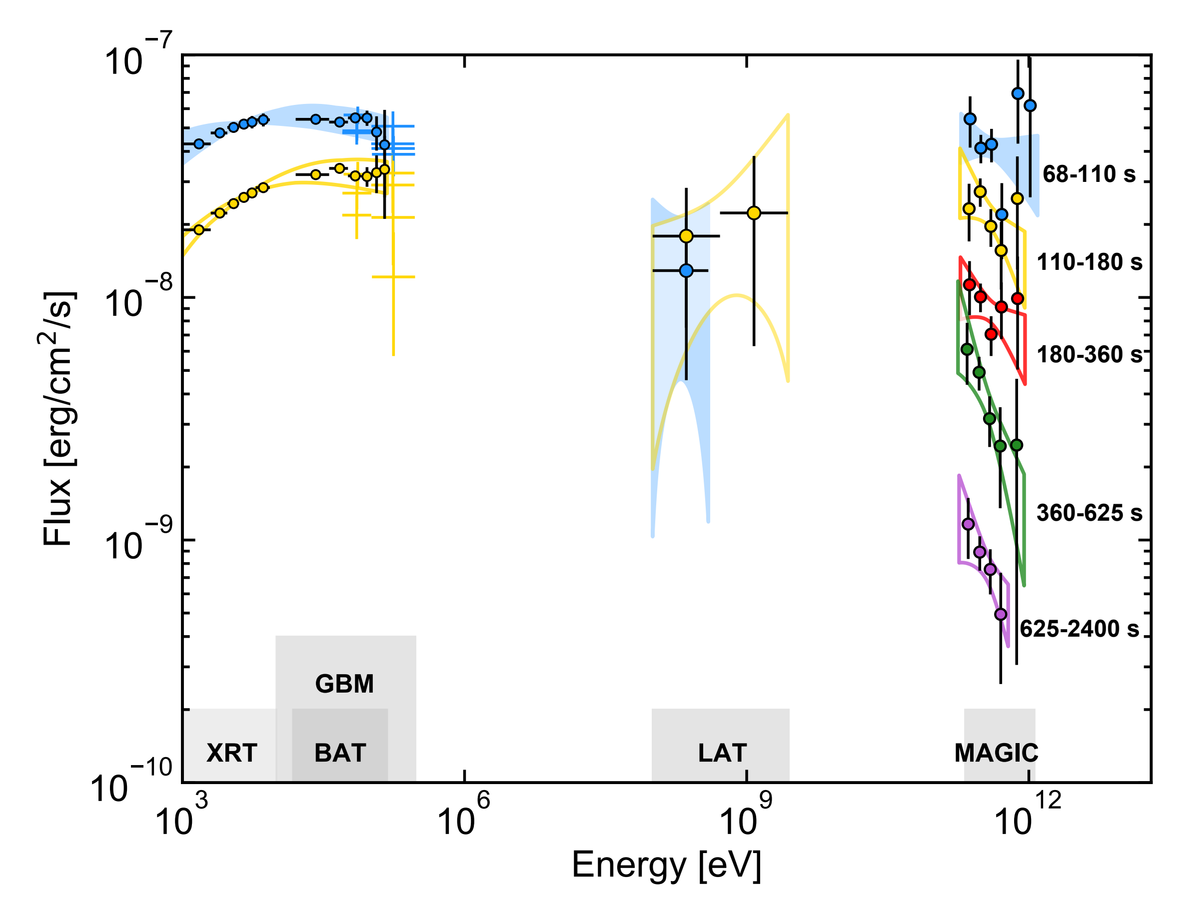


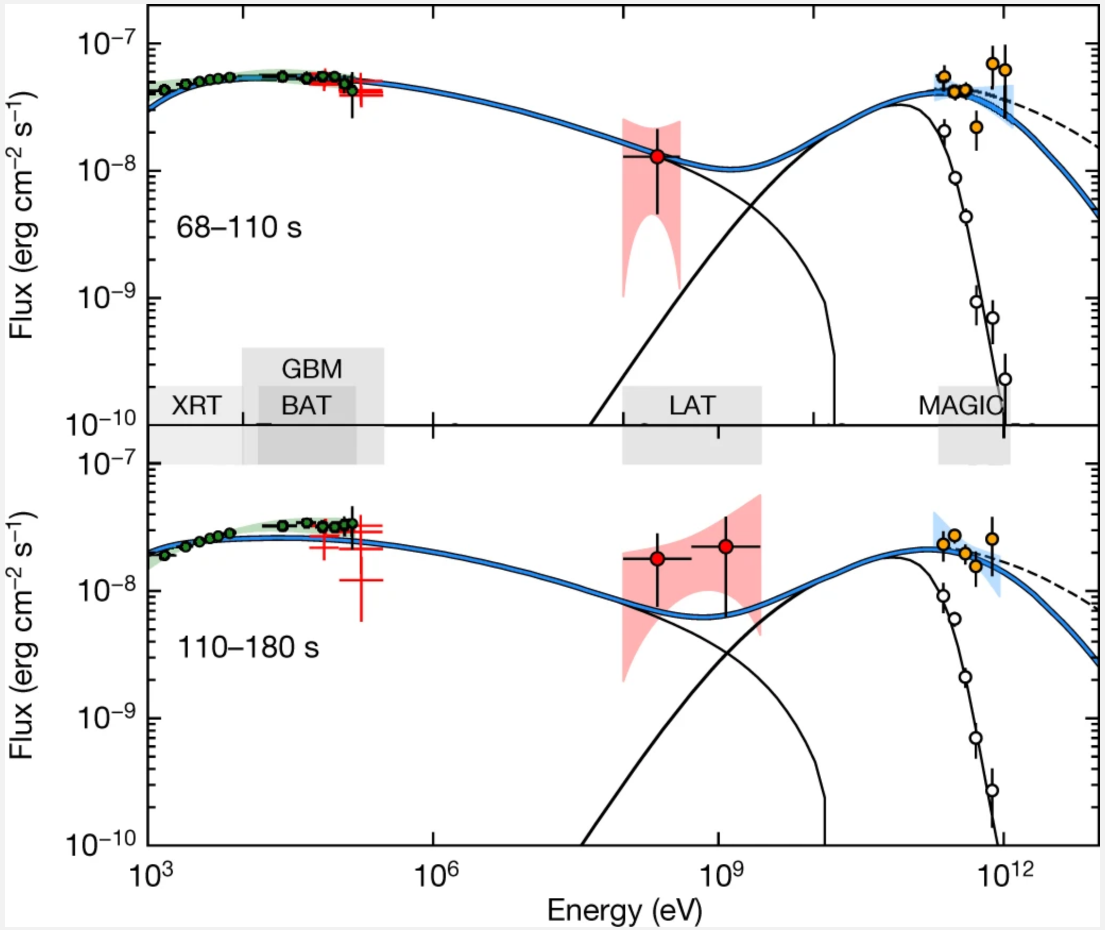
Miceli & Nava, 2022

GRB modeling

Responsible radiation mechanism: SSC

GRB190114C



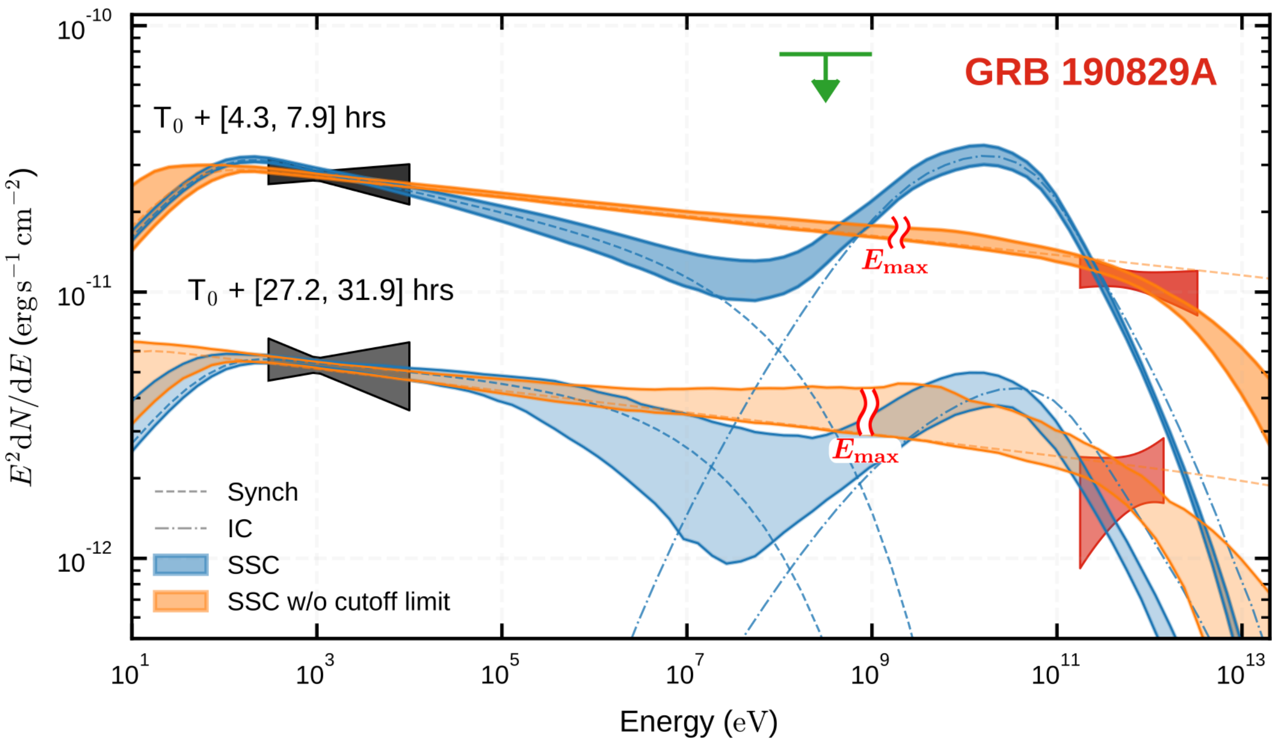


MAGIC Coll. et al., 2019

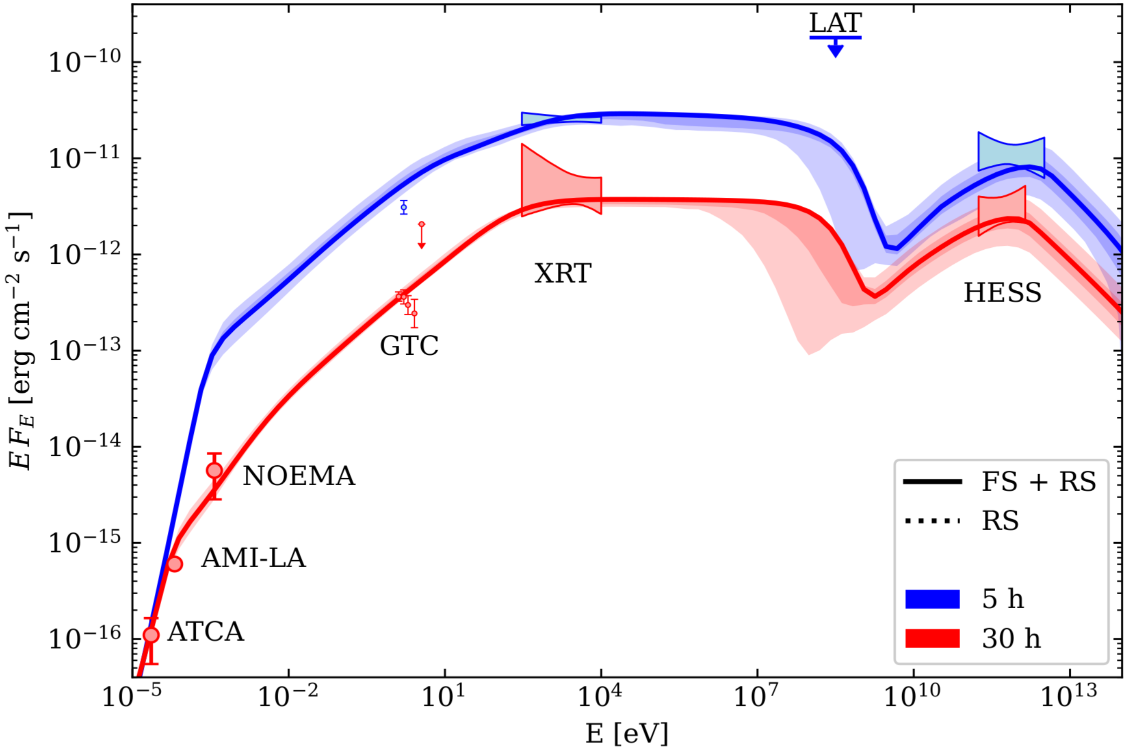
GRB modeling

Responsible radiation mechanism: Sync? SSC?

GRB190829A



HESS Coll., 2021

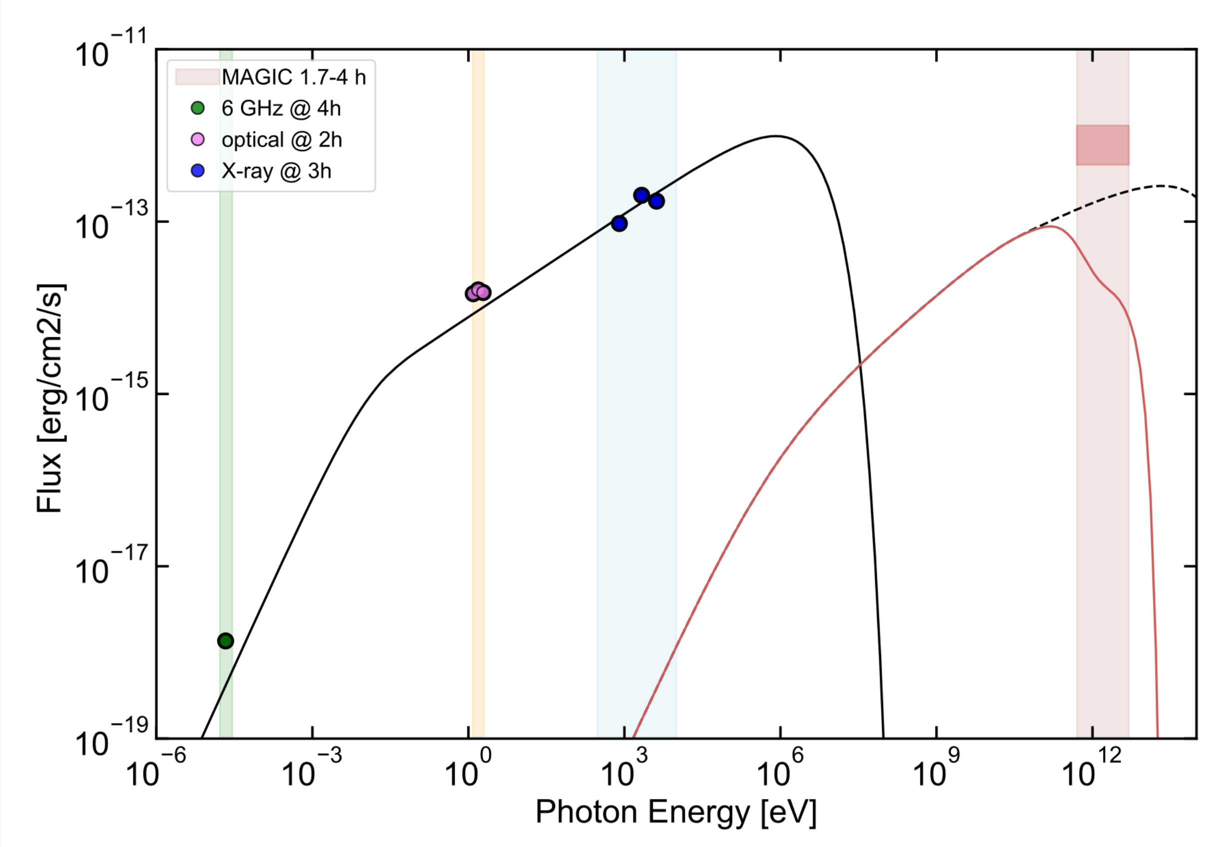


Salafia et al., 2021

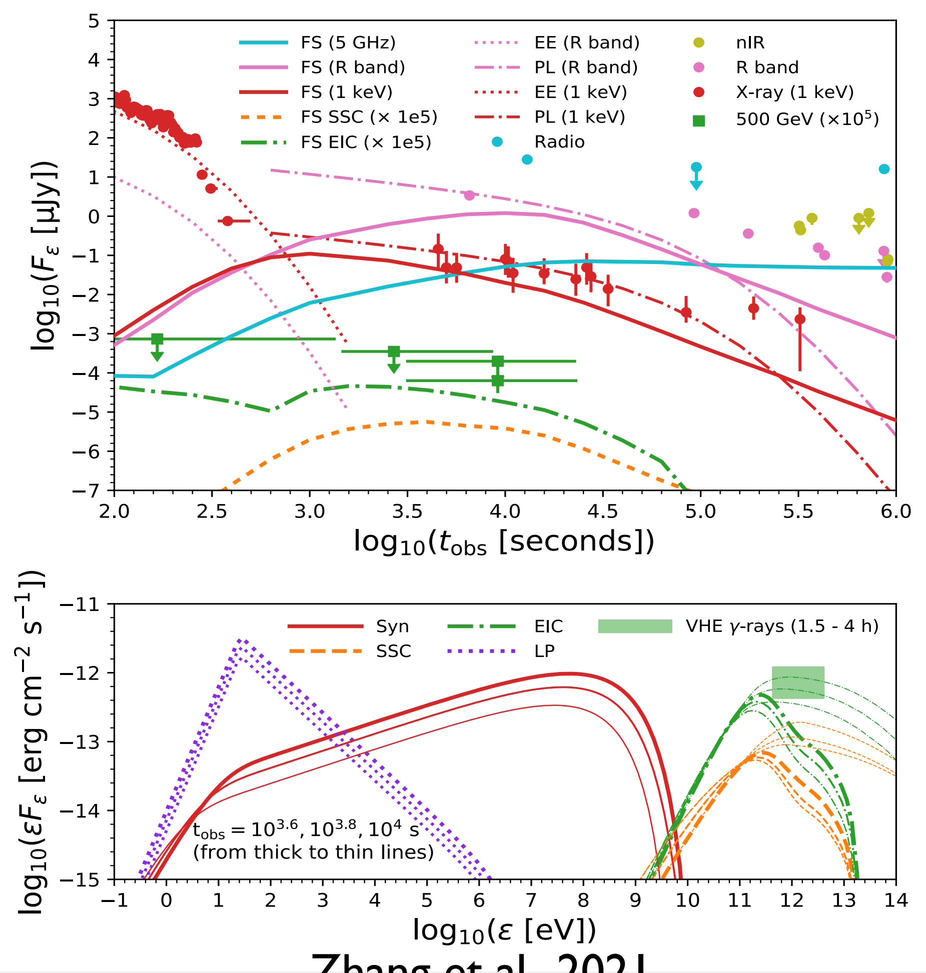
GRB modeling

Responsible radiation mechanism: EIC? SSC?

GRB160821B (3σ excess)



MAGIC Coll., 2021



Zhang et al., 2021

GRB modeling

Model free parameters (GRB environment, shock microphysics)

	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

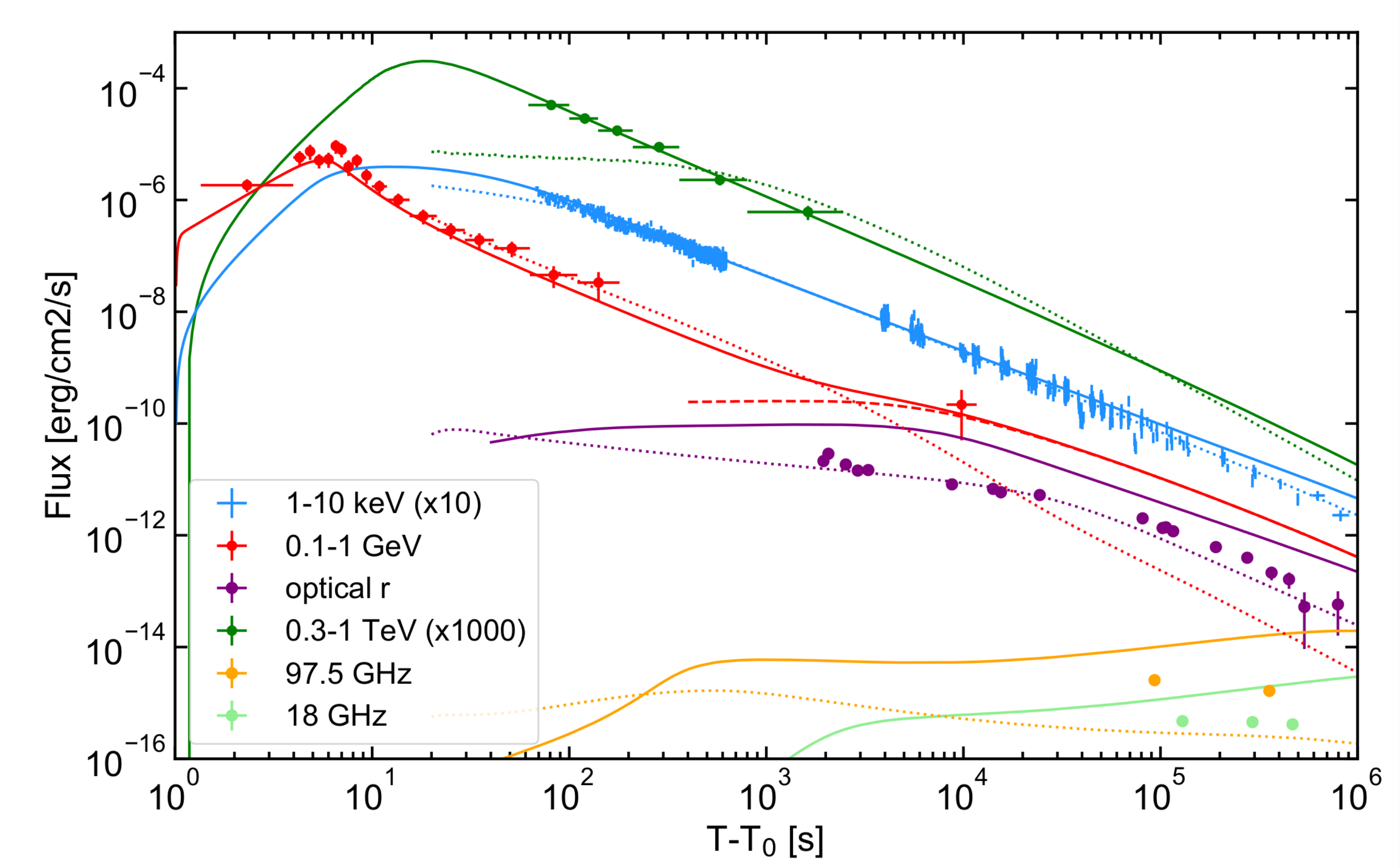
	E_k erg	ϵ_e	ϵ_B	n cm^{-3}	p	ξ_e
MAGIC Coll.	$\gtrsim 3 \times 10^{53}$	0.05-0.15	0.05-1 $\times 10^{-3}$	0.5-5	2.4-2.6	1
Wang + 2019	6×10^{53}	0.07	4×10^{-5}	0.3	2.5	1
Asano + 2020	10^{54}	0.06	9×10^{-4}	1	2.3	0.3
Asano + 2020	10^{54}	0.08	1.2×10^{-3}	0.1 (wind)	2.35	0.3
Joshi + 2021	4×10^{54}	0.03	0.012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

	E_k erg	$\log(\epsilon_e)$	$\log(\epsilon_B)$	log(n) cm^{-3}	p	ξ_e	θ_j rad
MAGIC Coll.	$10^{51} - 10^{52}$	[-1 ; -0.1]	[-5.5 ; -0.8]	[-4.85 ; -0.24]	2.2-2.35	1	/
Troja + 2019	$10^{50} - 10^{51}$	[-0.39 ; -0.05]	[-3.1 ; -1.1]	[-4.2 ; -1.7]	2.26-2.39	1	0.08-0.50
Zhang + 2021 (SSC)	3×10^{51}	-0.52	-5	-1.3	2.3	0.5	0.15
Zhang + 2021 (EIC)	2×10^{51}	-0.3	-6	-1	2.5	0.1	0.1

GRB modeling

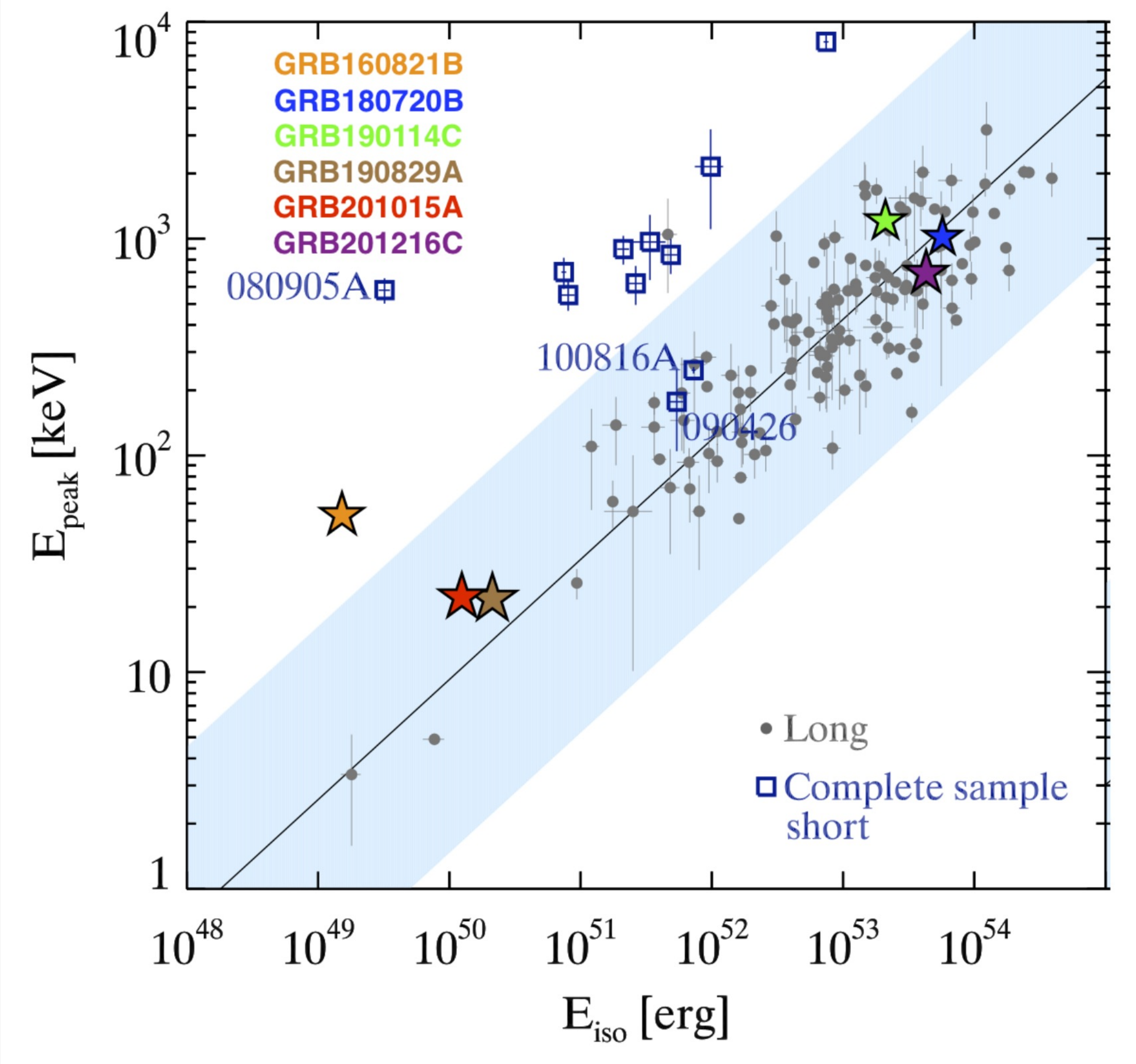
GRB190114C

- Sync+SSC external forward scenario
- Two modeling displayed:
  - X to TeV (solid lines)
  - Radio-optical (dotted lines)
  - SSC contribution (dashed lines)
- Indication of time-dependent afterglow parameters



Population of GRBs at VHE

- Broadband intrinsic properties:
  - span more than 3 orders of magnitude in $E_{\gamma,iso}$
  - span 2 orders of magnitude in terms of L_{VHE}
  - ranging in redshift between 0.079–1.1
- X-ray – TeV connection:
  - similar fluxes and decay slopes
  - similar amount of radiated power
- Data modeling:
  - SSC suggested (not conclusive)
  - no preferences on constant/wind-like medium
  - $\epsilon_e \sim 0.1$, $\epsilon_B \sim 10^{-5}$–10^{-3}, $\xi<1$



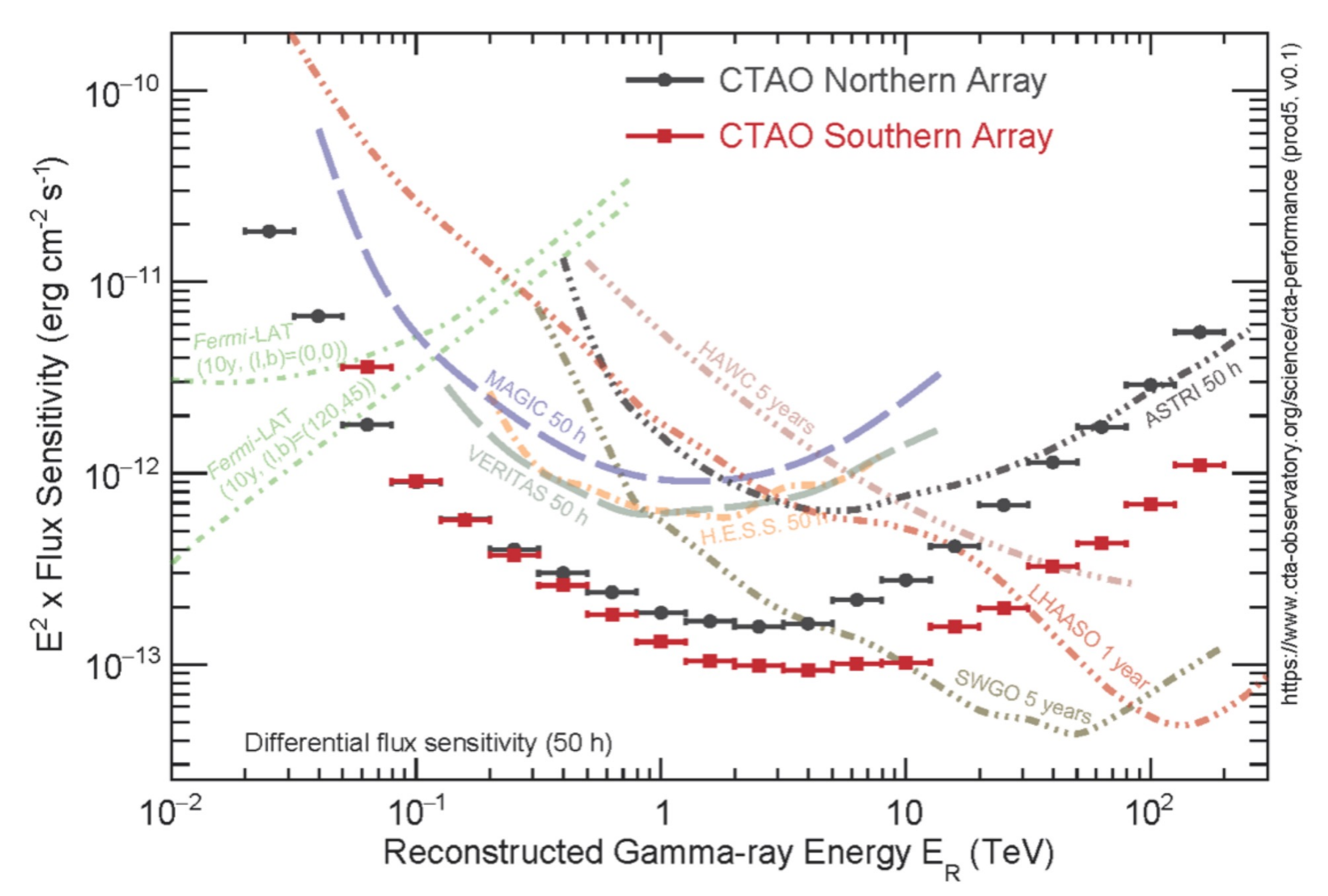
Miceli & Nava, 2022, adapted from D'Avanzo et al. 2014

Future facilities: CTA

CTA upgrades:

- a lower energy threshold (<30 GeV)
- a larger effective area at multi-GeV energies (~ 10^4 times larger than Fermi-LAT at 30 GeV)
- a rapid slewing capability (180 degrees azimuthal rotation in 20 s).
- a full sky coverage

A few GRBs per year…



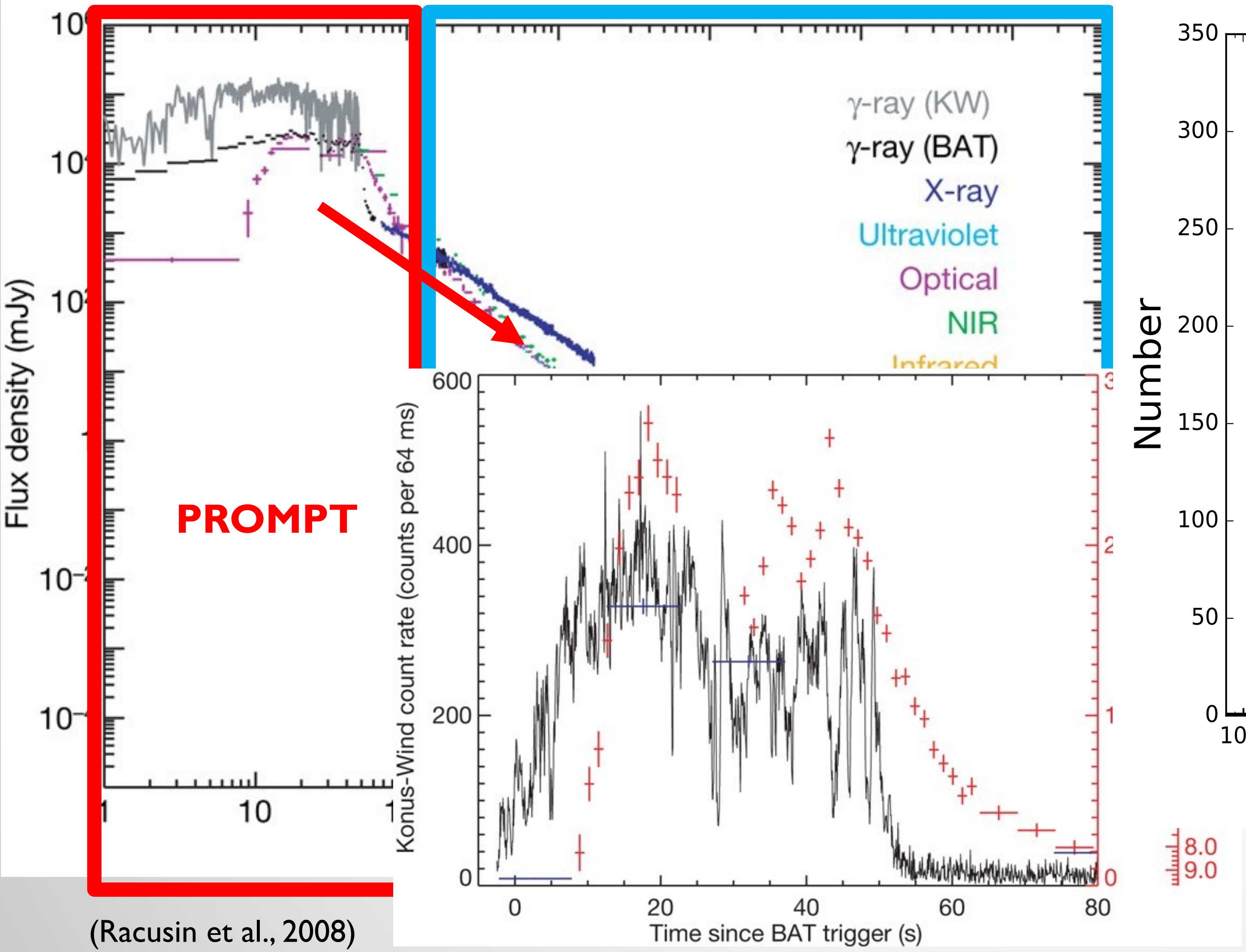
https://www.cta-observatory.org/science/ctao-performance/

Future challenges

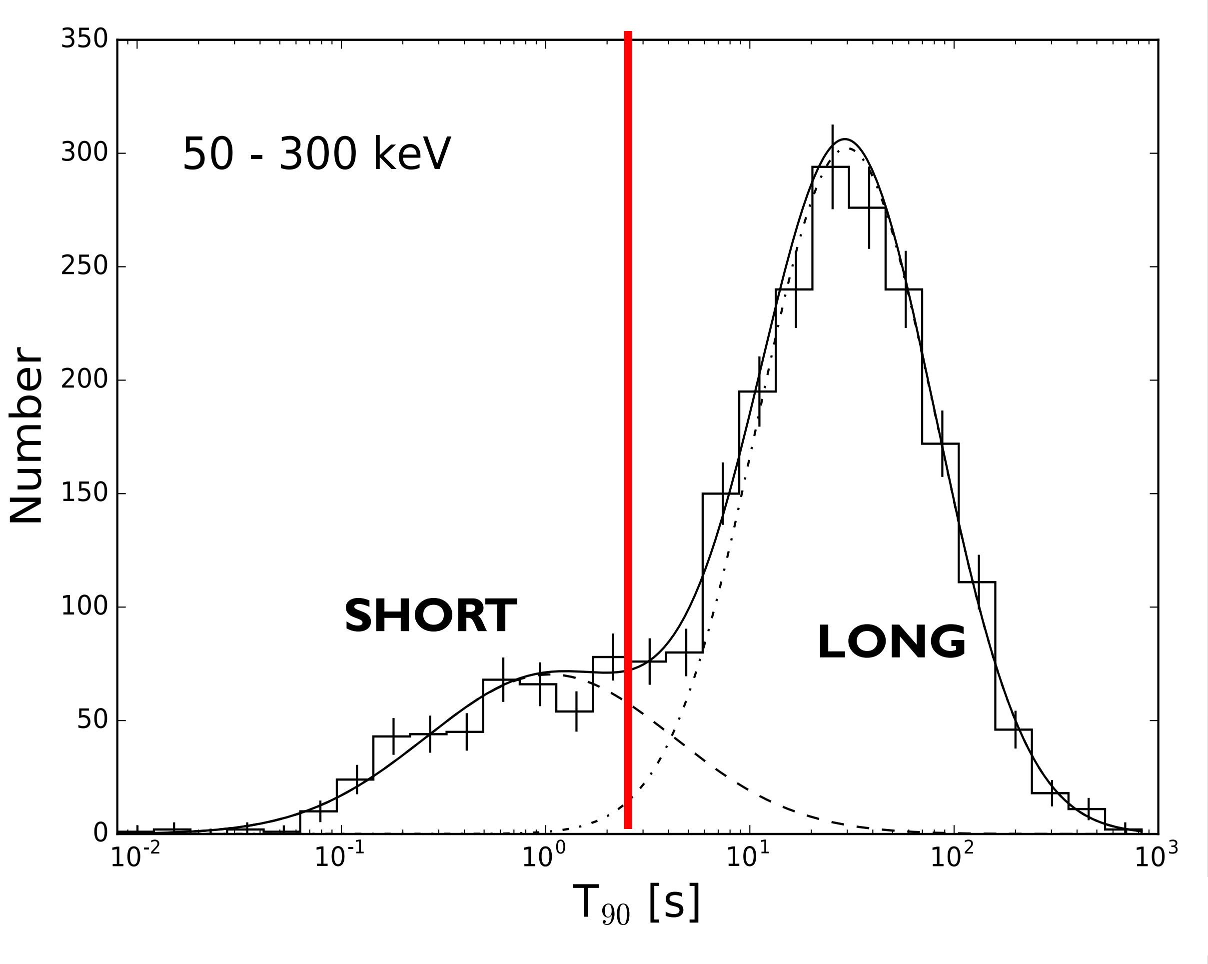
- Test responsible radiation mechanisms (SSC, Syn)
- Investigate conditions for VHE emission (GRB environment, microphysics, jet dynamics)
- VHE in short GRBs (so far only small hint of GRB160821B)
- VHE emission in prompt phase

BACKUP

Prompt phase

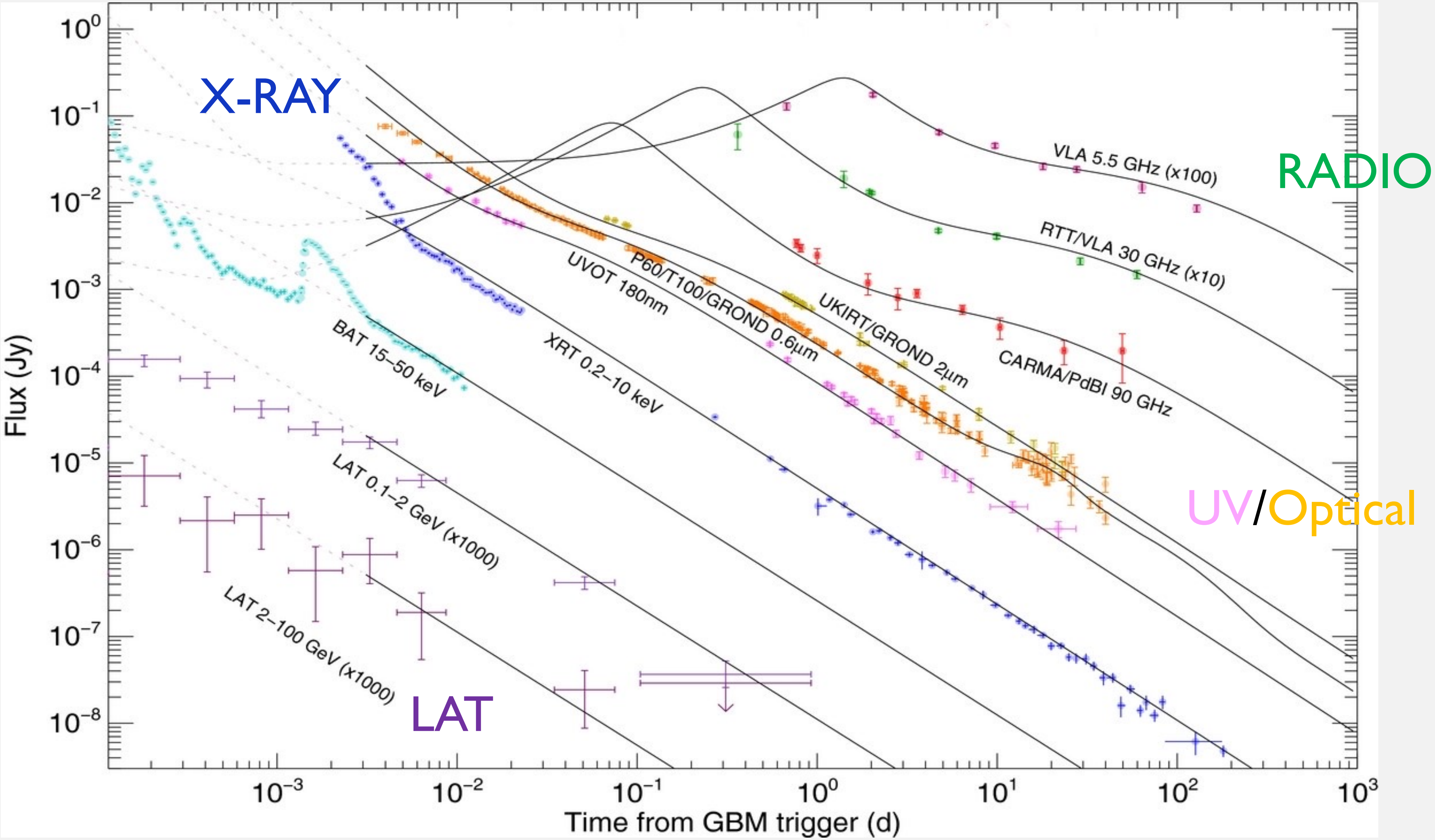


(Racusin et al., 2008)



(von Kienlin et al., 2020)

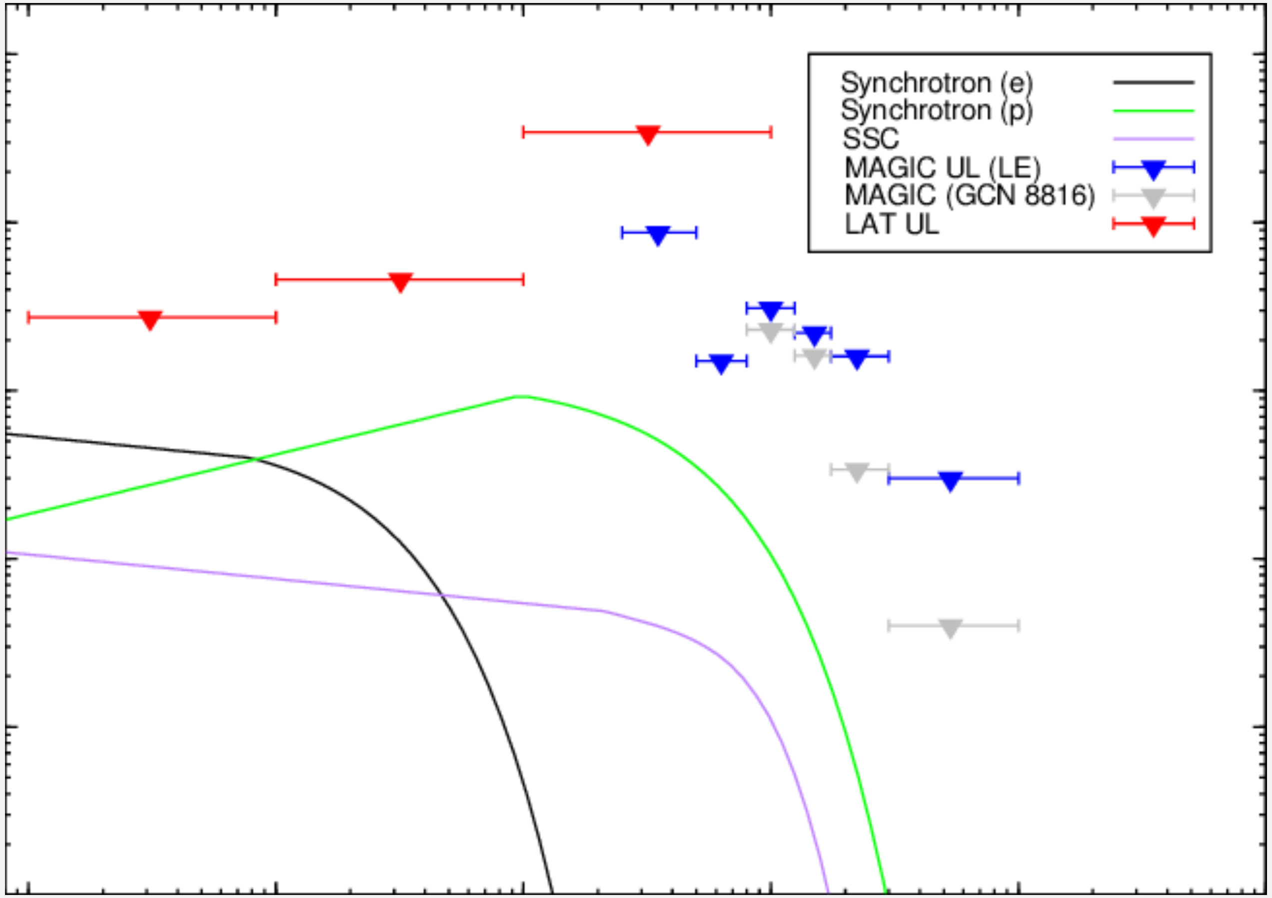
Afterglow phase



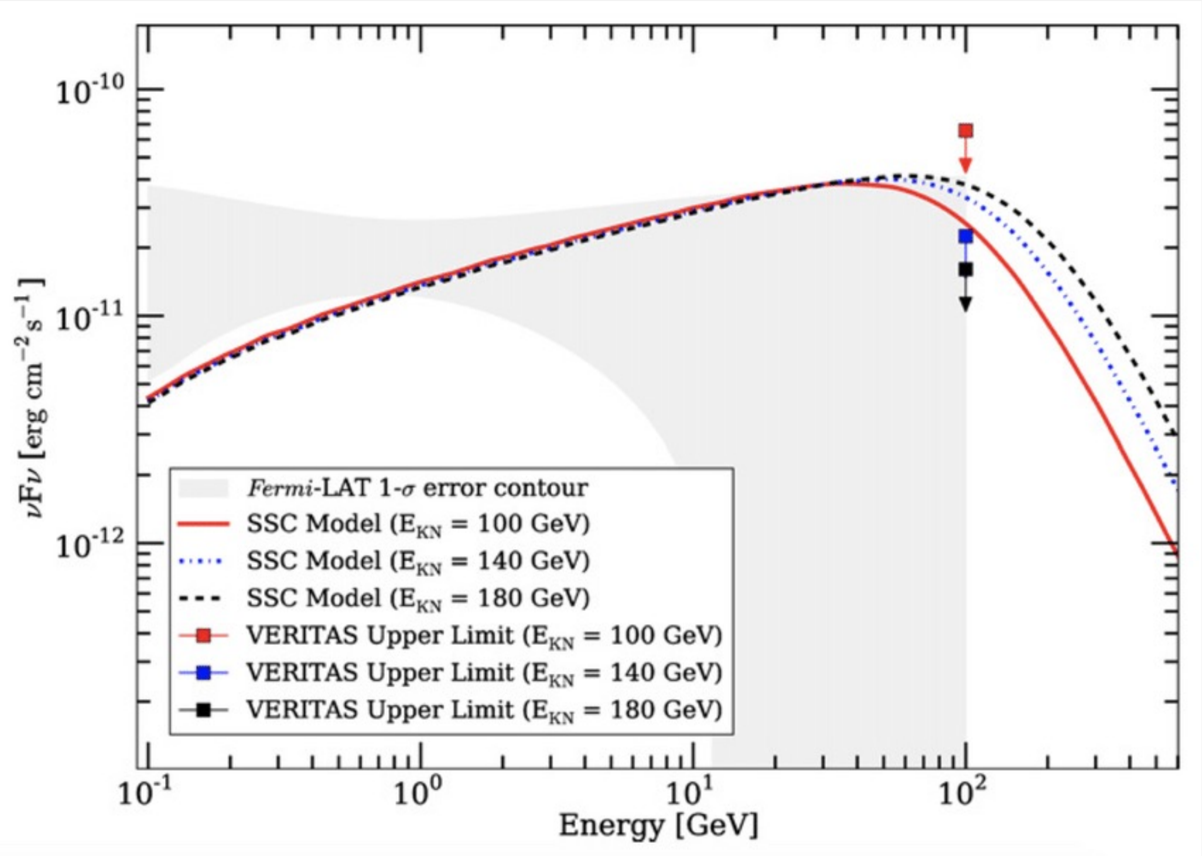
GRB130427A (Perleay et al., 2014)

VHE emission

Cherenkov telescope observations: only upper limits until 2019



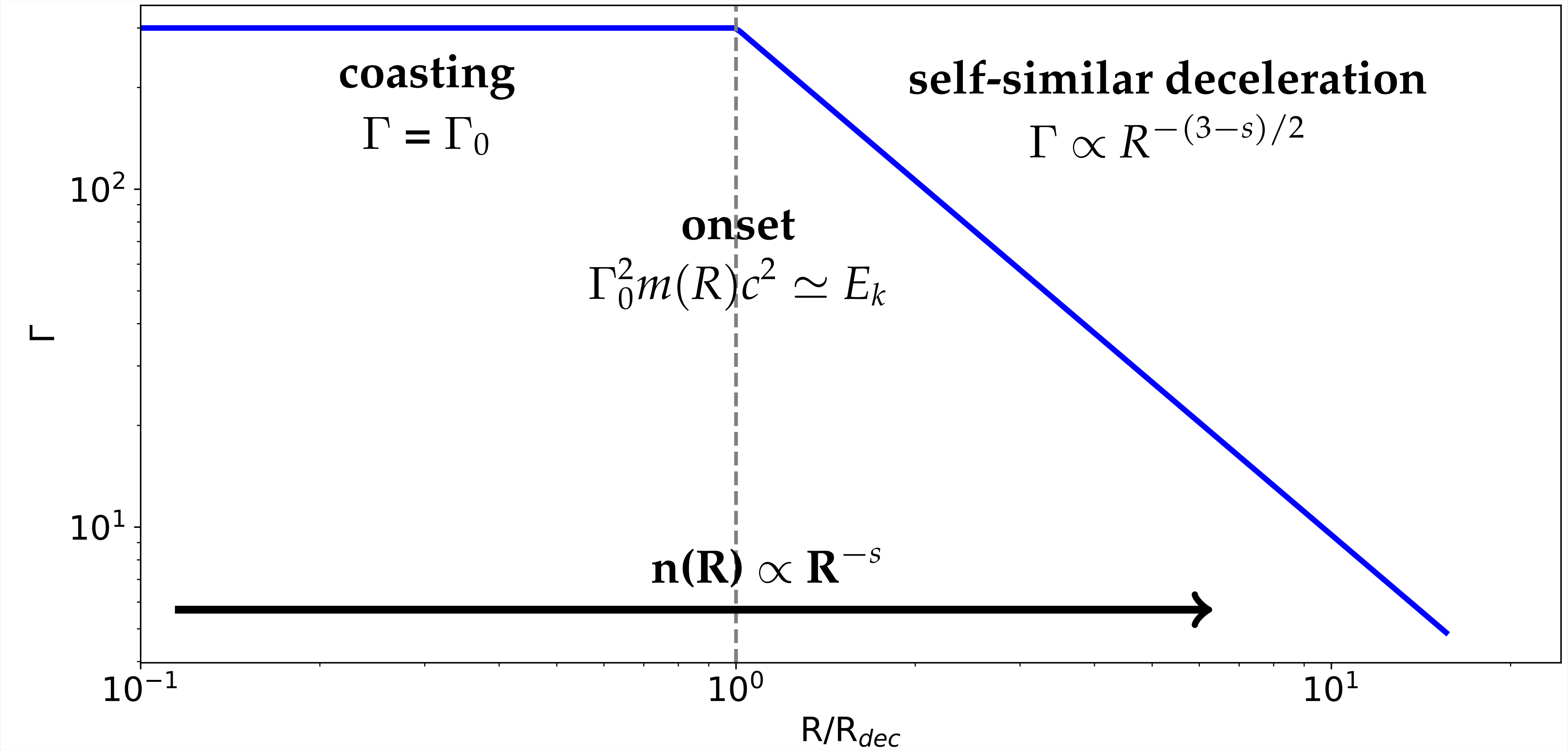
Aleksic et al. 2014



Aliu et al., 2014

Afterglow: the external forward shock scenario

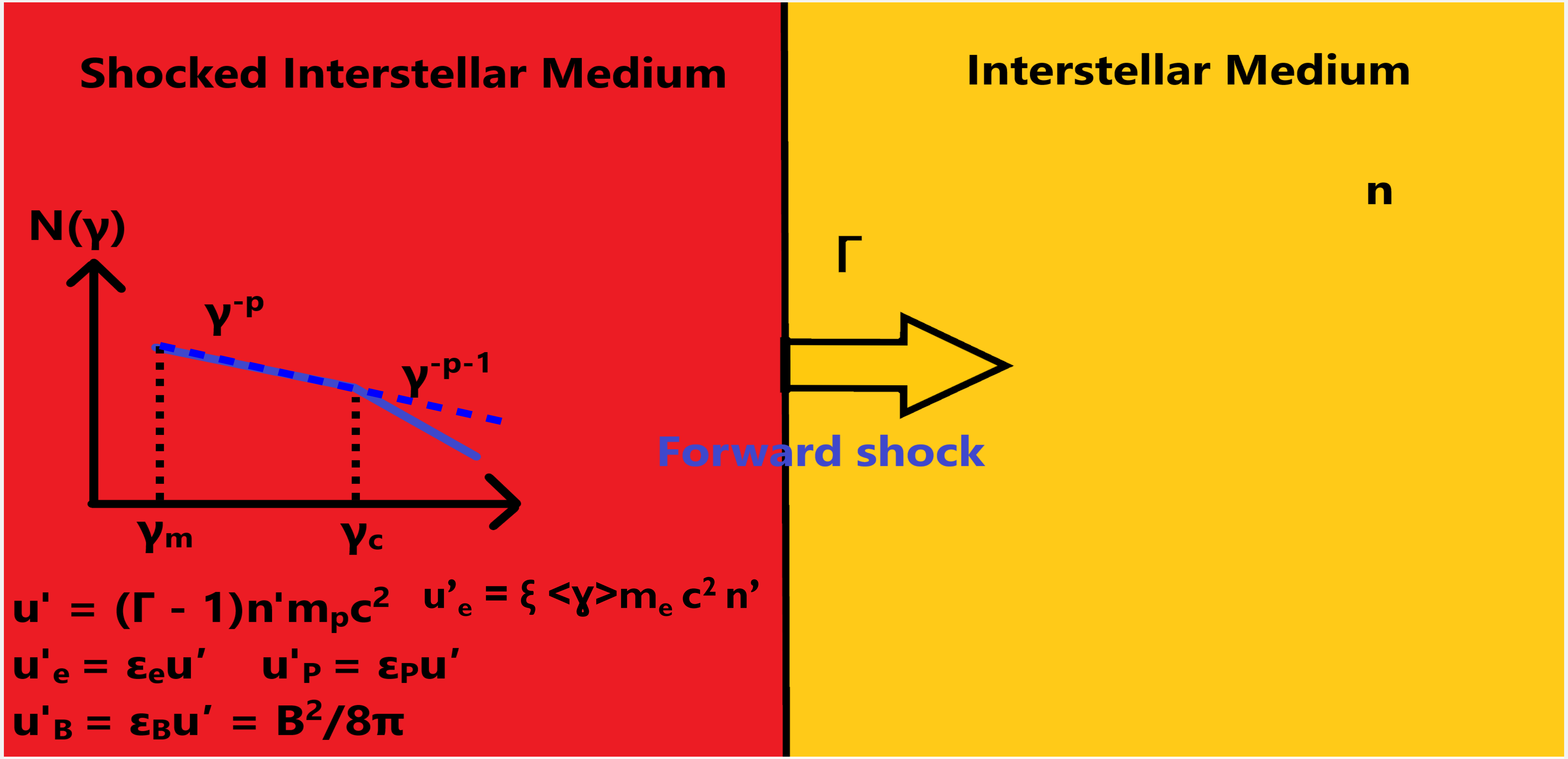
Jet dynamics



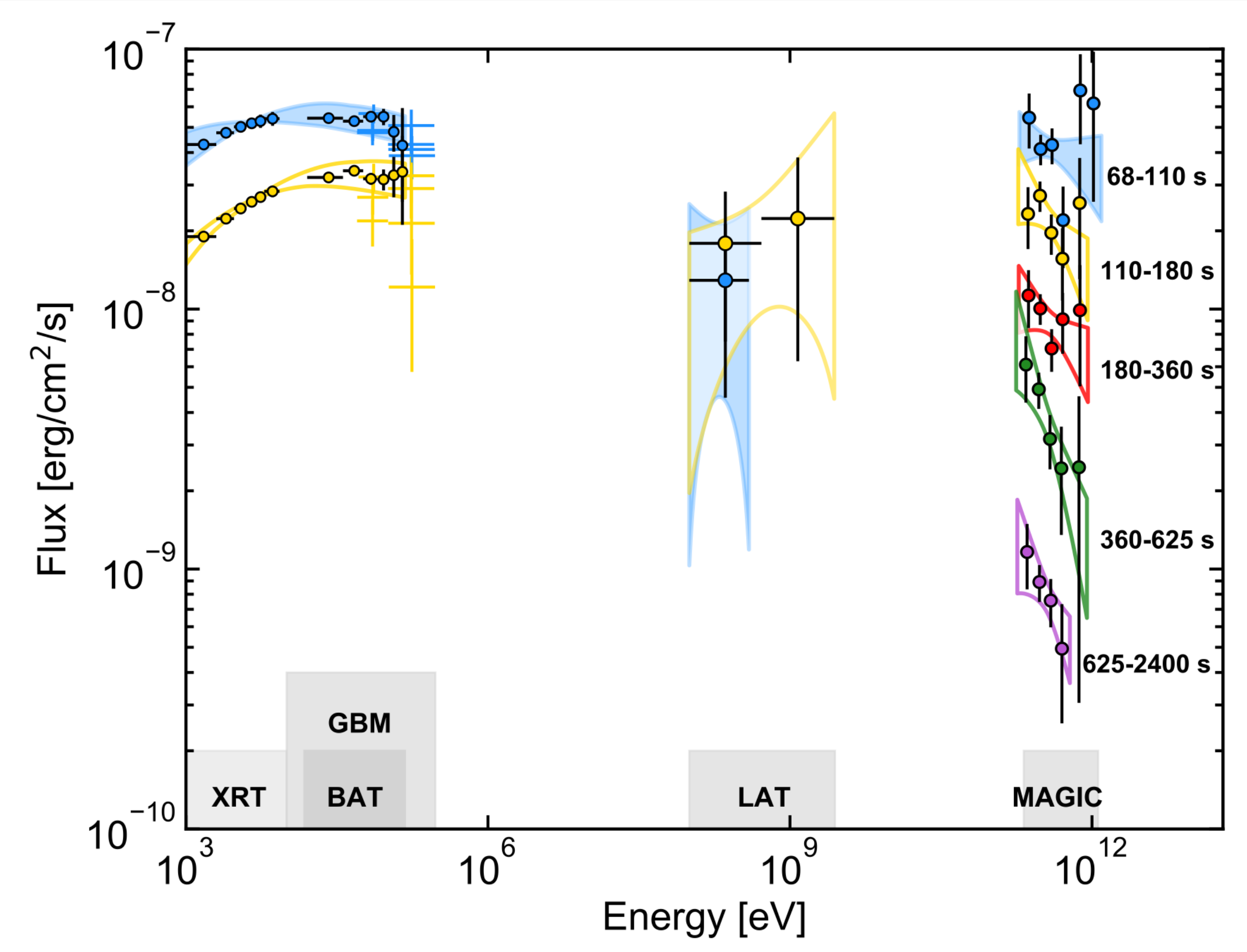
See Blandford & Mckee, 1976; Nava et al., 2014

Afterglow: the external forward shock scenario

Relativistic shocks in GRB afterglow



GRB190114C



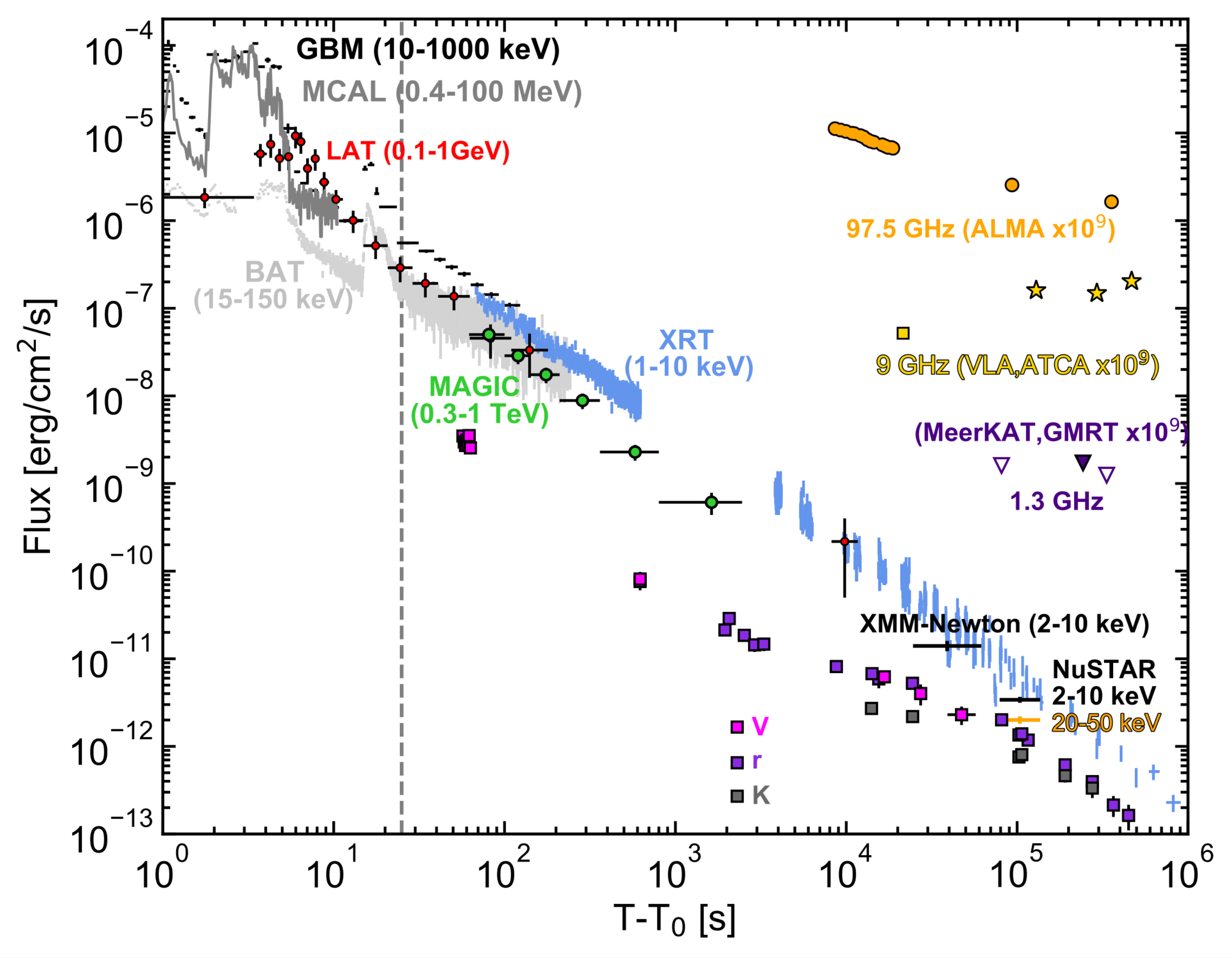
MAGIC Coll. et al., 2019

GRB190114C

- Long GRB
- $E_{\gamma,iso} \sim 2.5 \times 10^{53}$ erg
- z = 0.42

MAGIC detection info:

- $T_{delay} \sim 57$ s
- > 50σ in 20 minutes
- detection up to 40 min
- 0.3 - 1 TeV energy range
- moon conditions and Zd>50



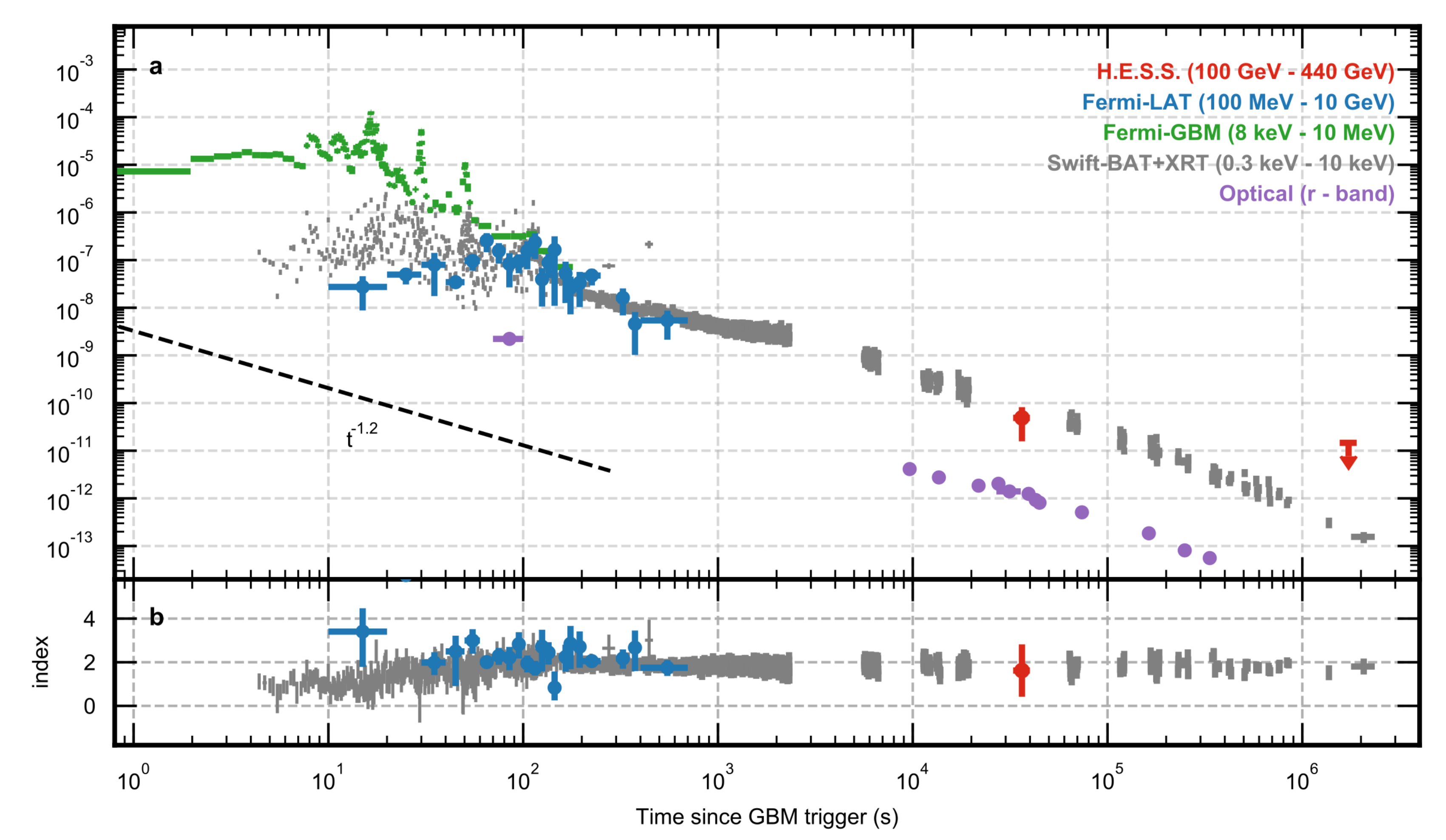
MAGIC Coll. et al., 2019

GRB180720B

- Long GRB
- $E_{\gamma,iso} \sim 6.0 \times 10^{53}$ erg
- z = 0.654

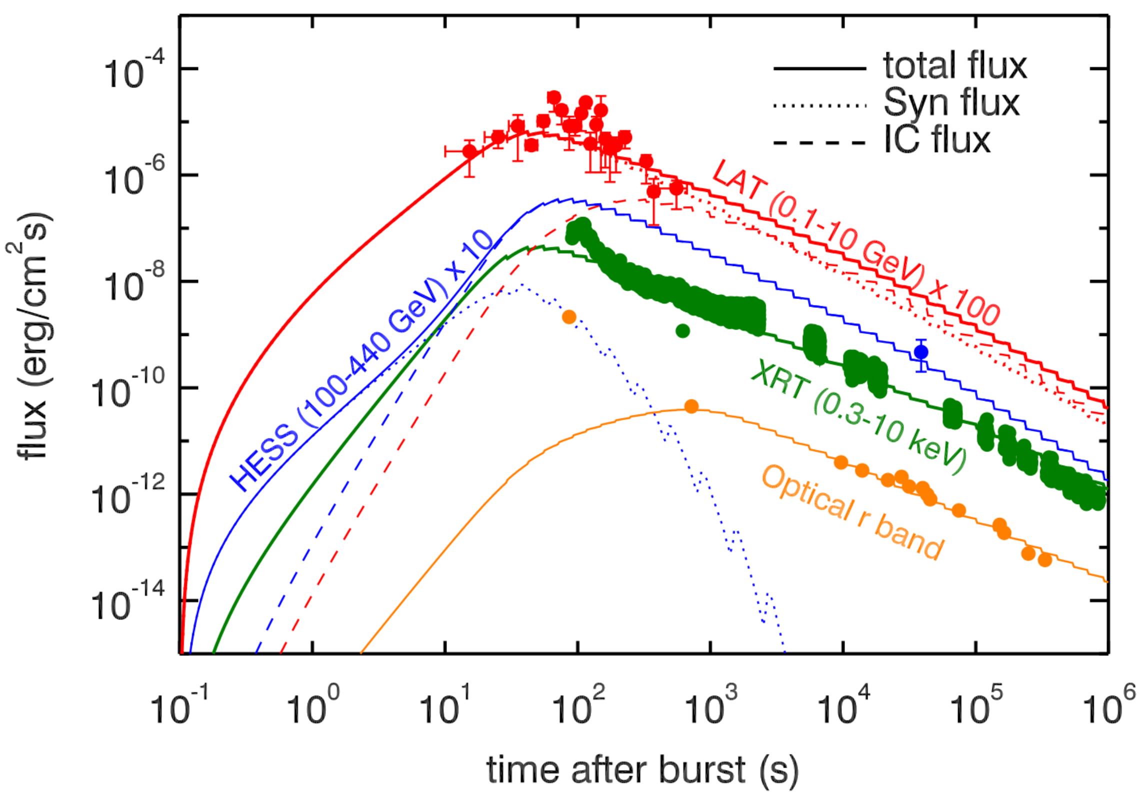
H.E.S.S. detection info:

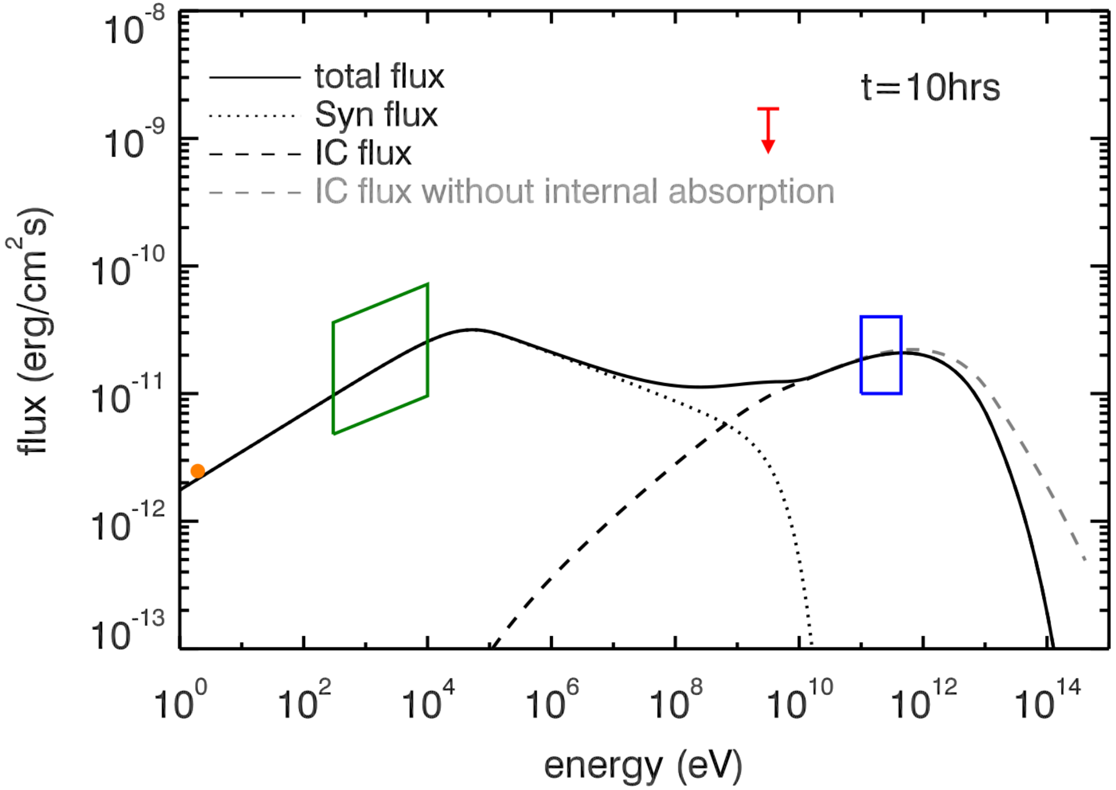
- Tdelay ~ 10 hrs
- > 5.3σ in 2 hrs
- 0.1 – 0.44 TeV energy range



HESS Coll., 2019

Modeling of GRB180720B





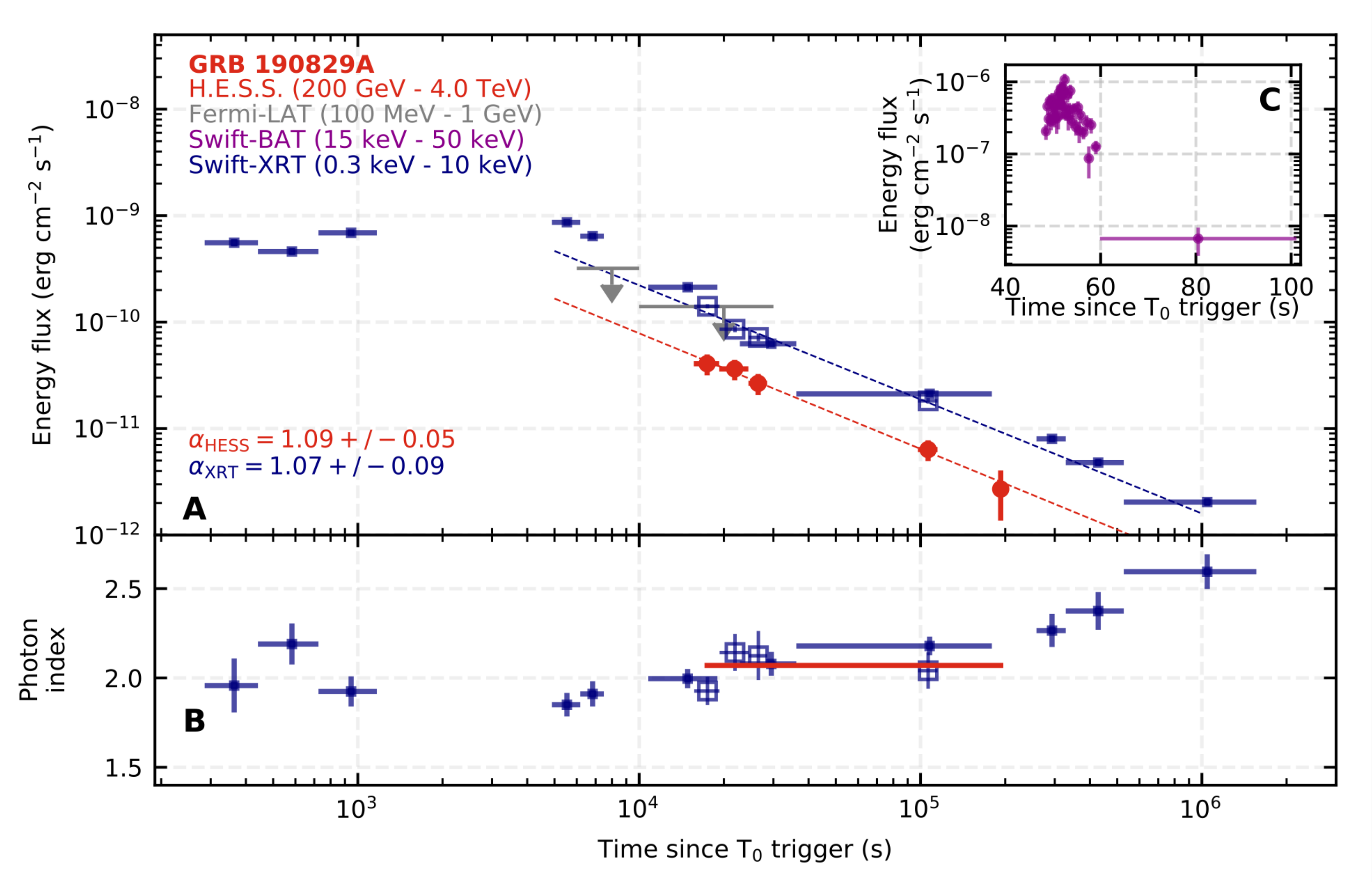
Wang et al.,2019

GRB190829A

- Long GRB
- $E_{\gamma,iso}$ ~ 2.0 x 10^{50} erg
- z = 0.079

H.E.S.S. detection info:

- T_{obs} ~ 4.3 - 55.9 hrs
- 21.7σ, 5.5σ, 2.4σ,
- 0.18 – 3.3 TeV energy range



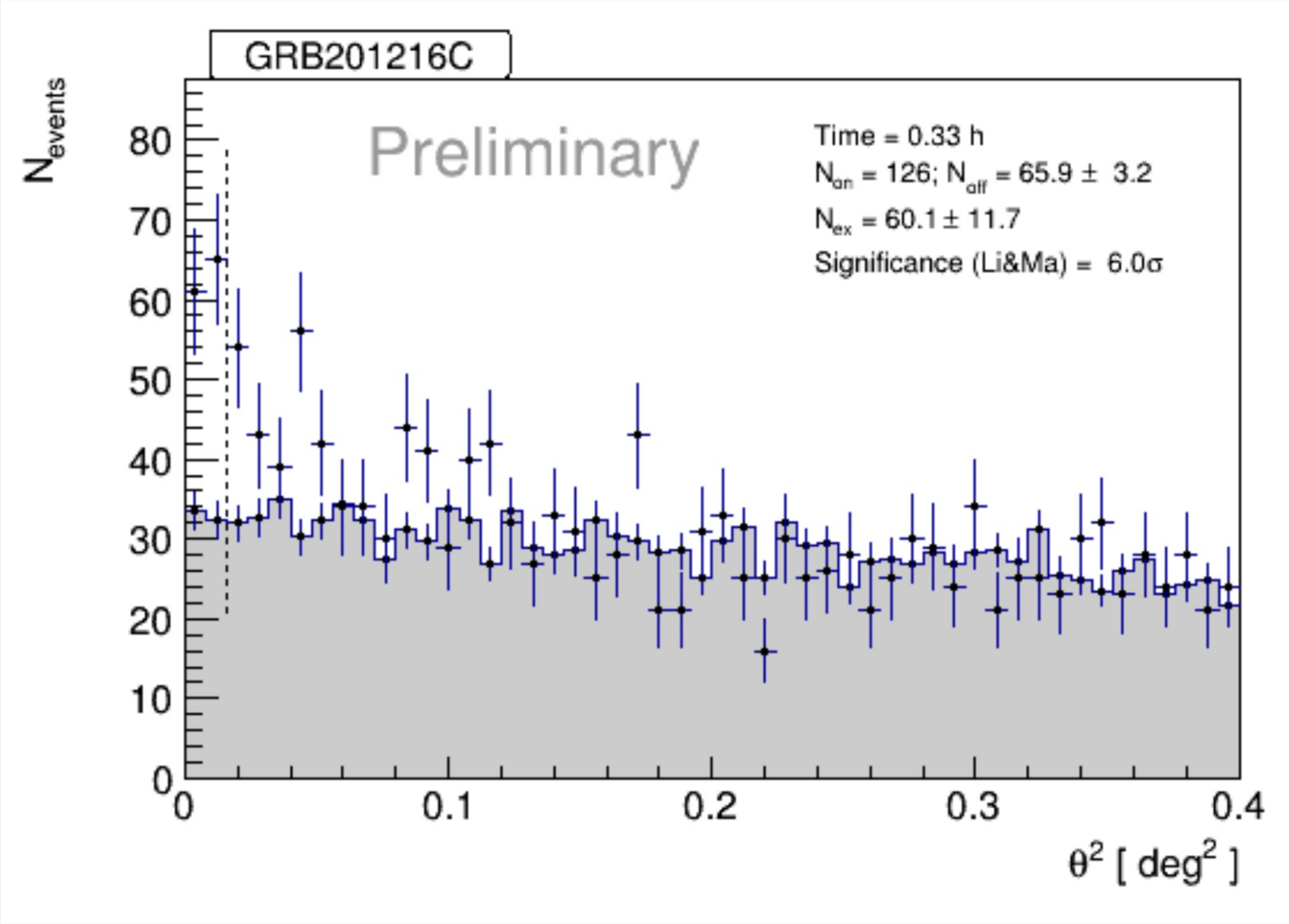
HESS Coll., 2021

GRB201216C

- Long GRB
- $E_{\gamma,iso} \sim 4.7 \times 10^{53}$ erg
- z = 1.1

MAGIC detection info:

- Tdelay ~ 56 s
- 6σ in 20 minutes
- 0.1 - ? TeV energy range



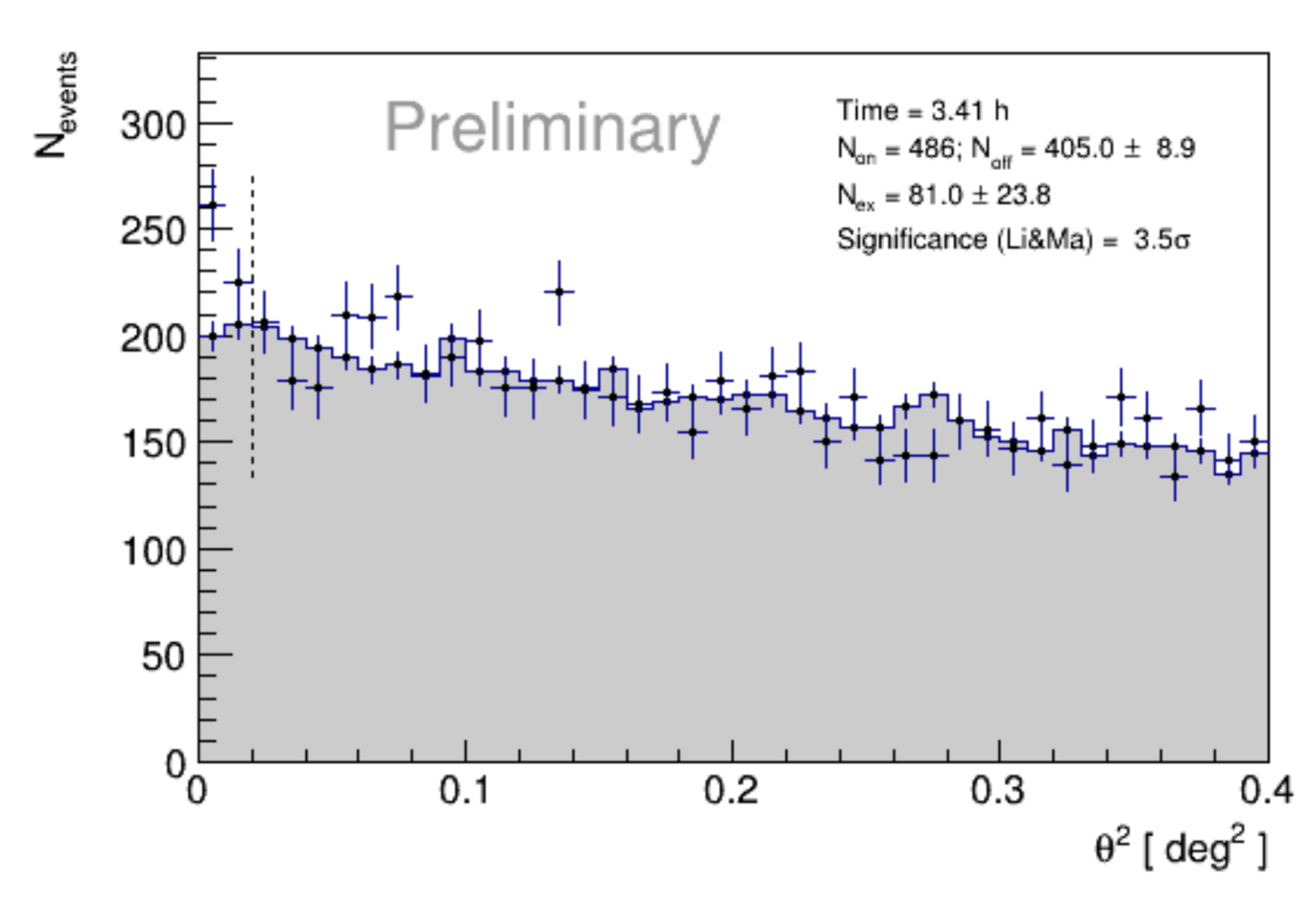
Suda et al., 2021, ICRC

GRB201015A (>3σ excess)

- long GRB
- $E_{\gamma,iso} \sim 1.1 \times 10^{50}$ erg
- z = 0.426

MAGIC info:

- Tdelay ~ 33 s
- 3.5σ in 3.4 hrs
- 0.14 - ? TeV energy range



Fukami et al., 2021, ICRC