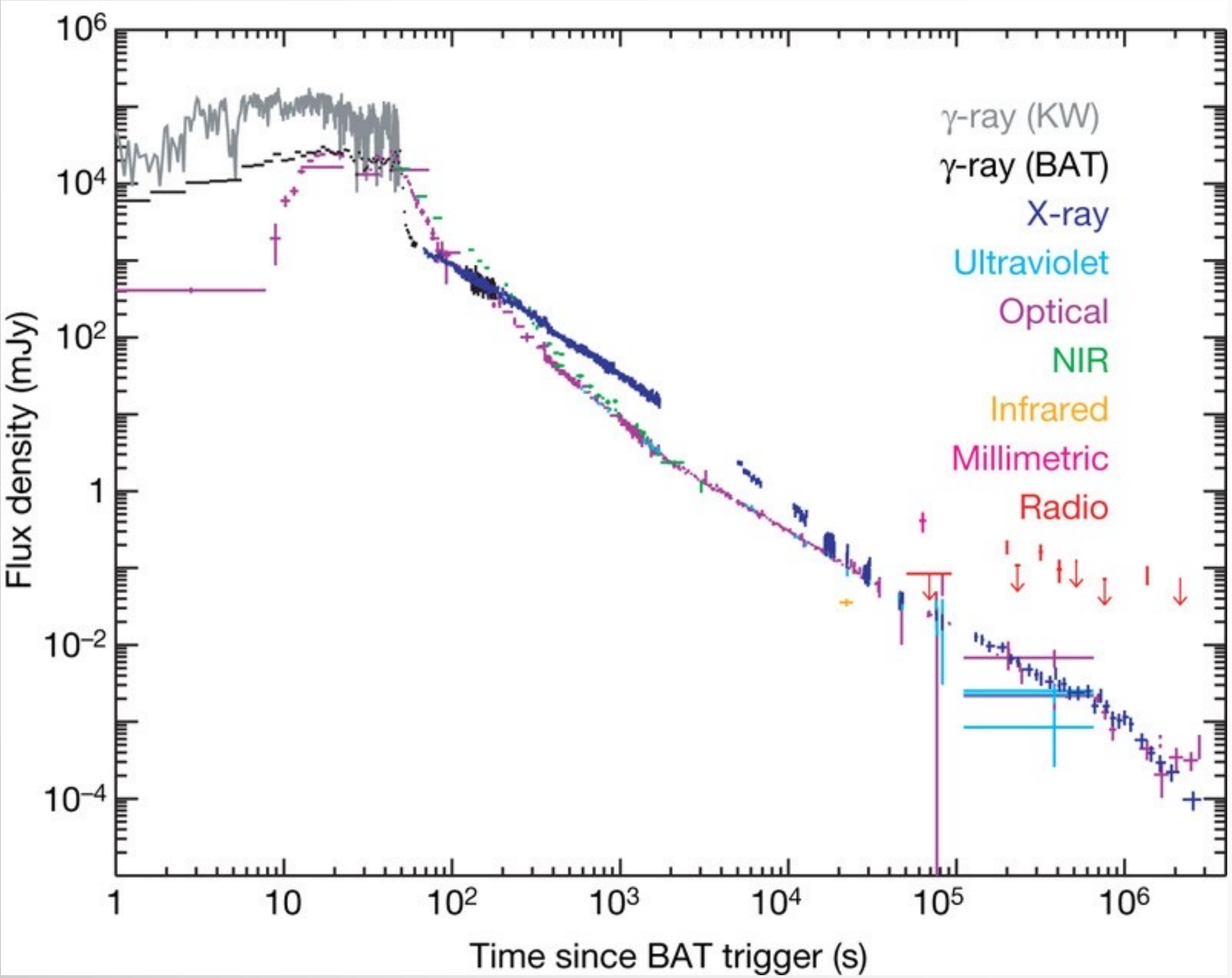
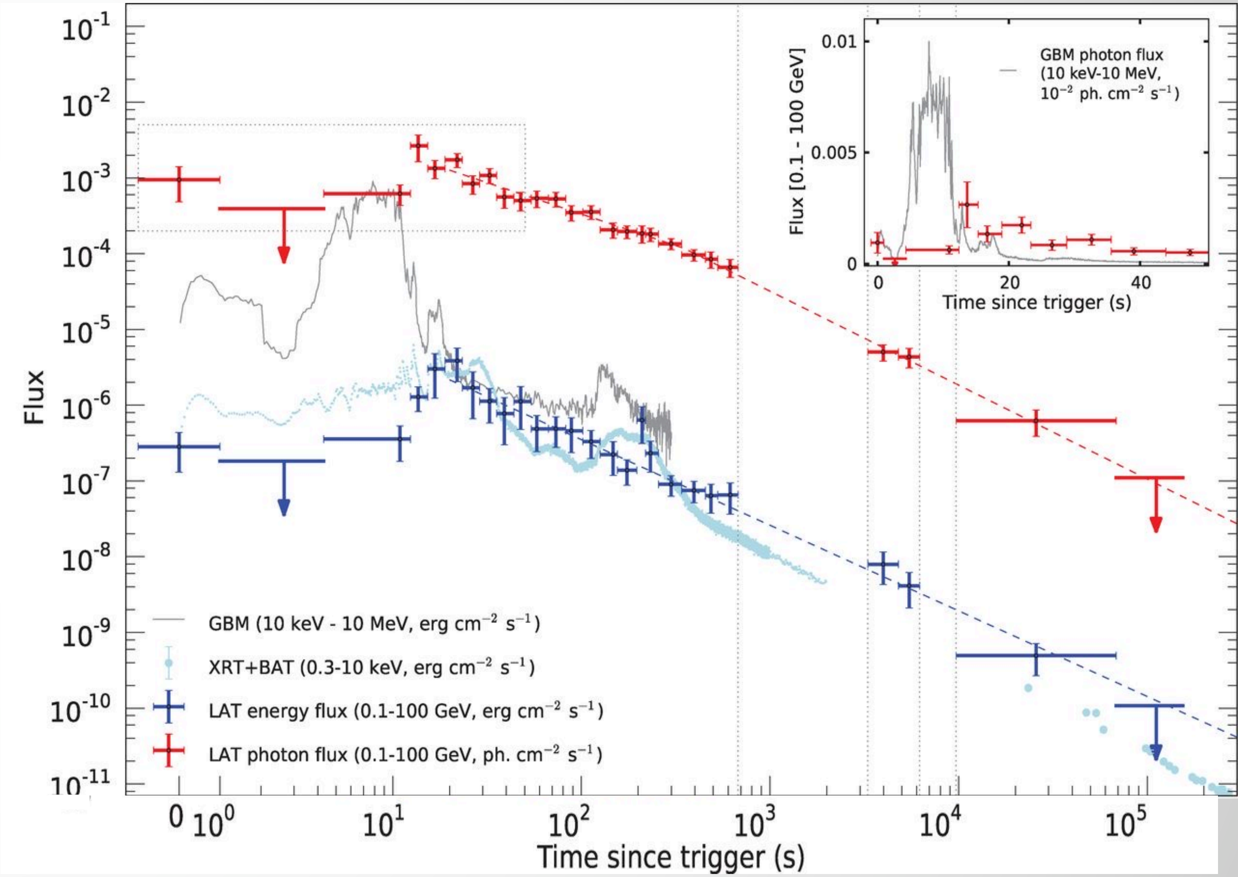
HIGH ENERGY RADIATION PROCESSES IN GRBs

Davide Miceli (University & INFN Padova)

Emission in Gamma-ray Bursts

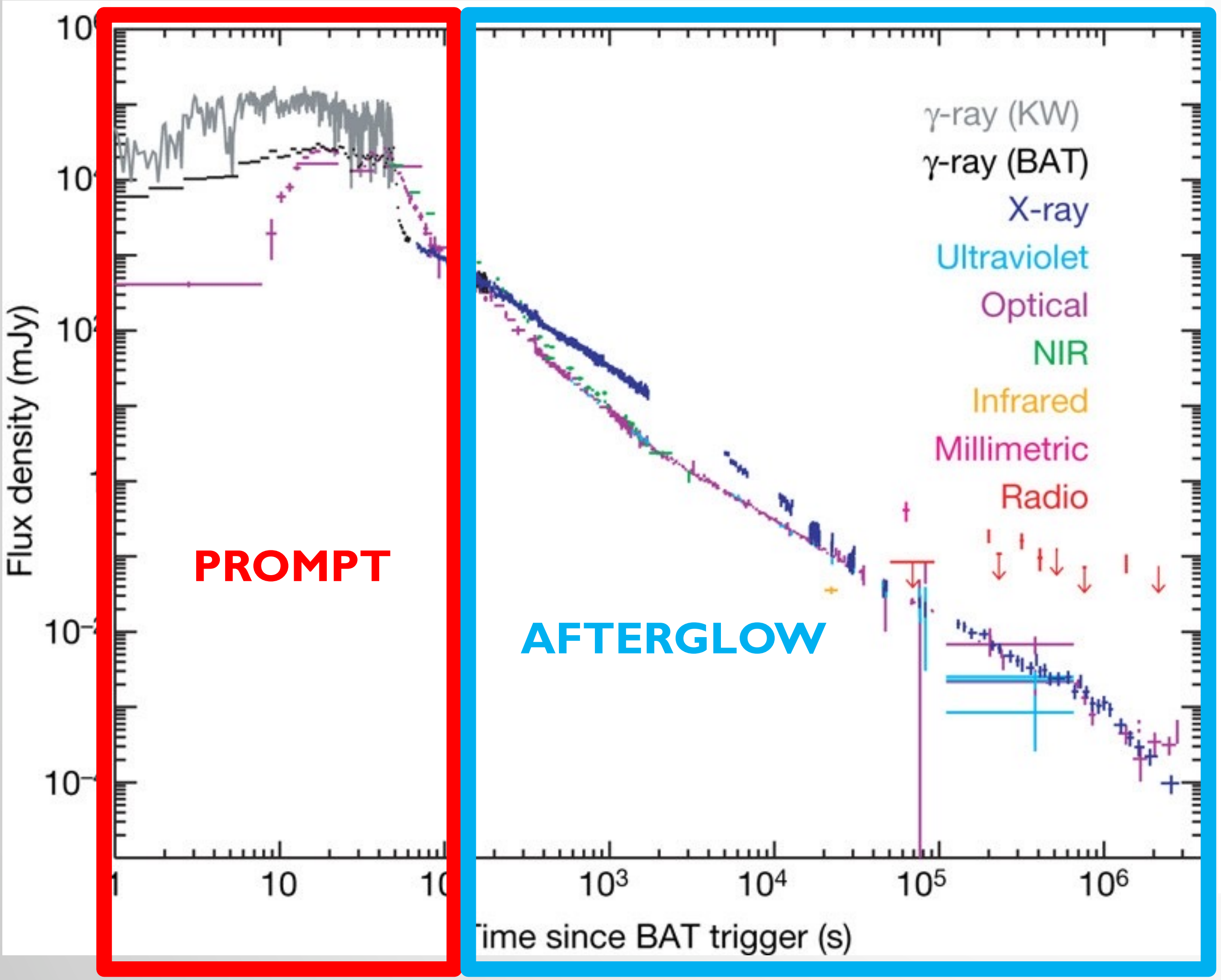




GRB130427A (Ackermann et al., 2013)

GRB080319B (Racusin et al., 2008)

Emission in Gamma-ray Bursts



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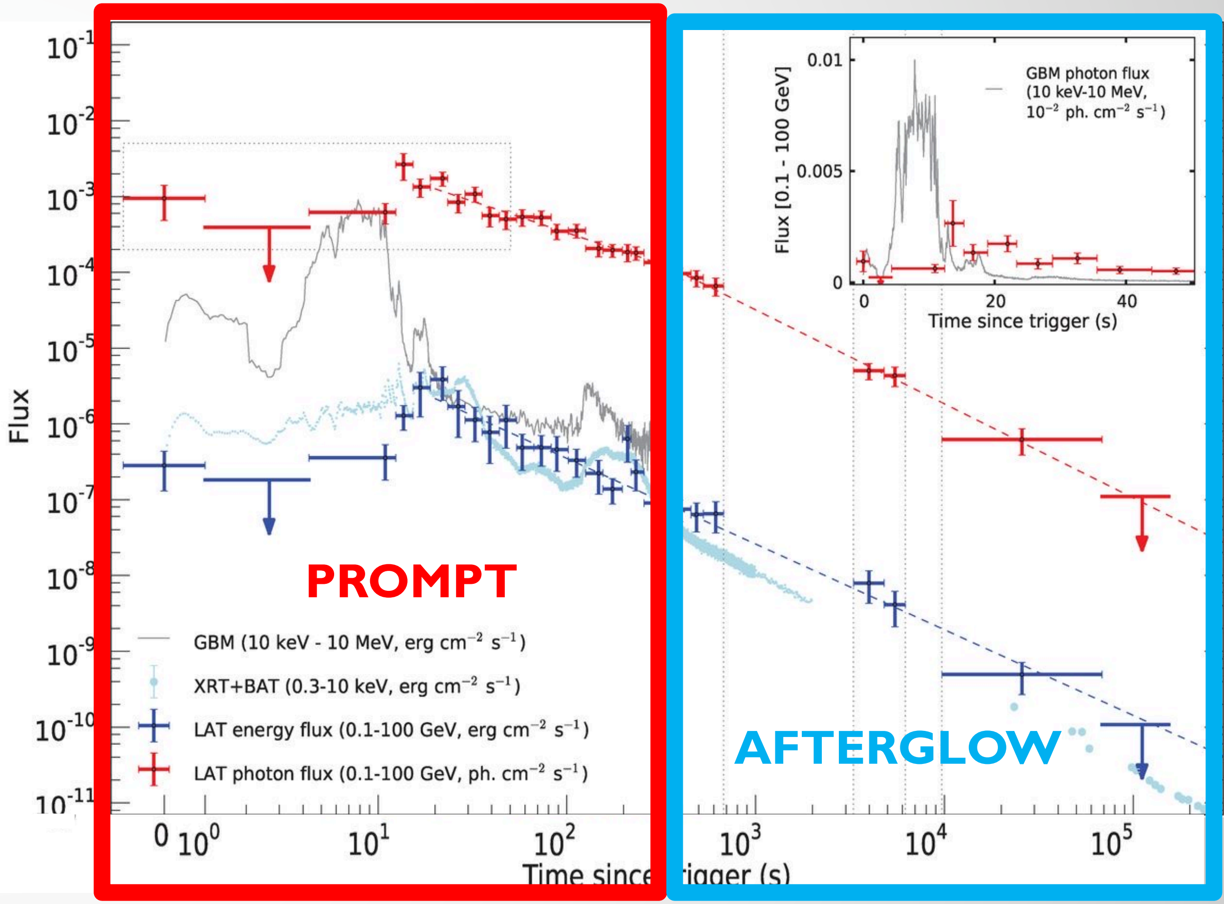
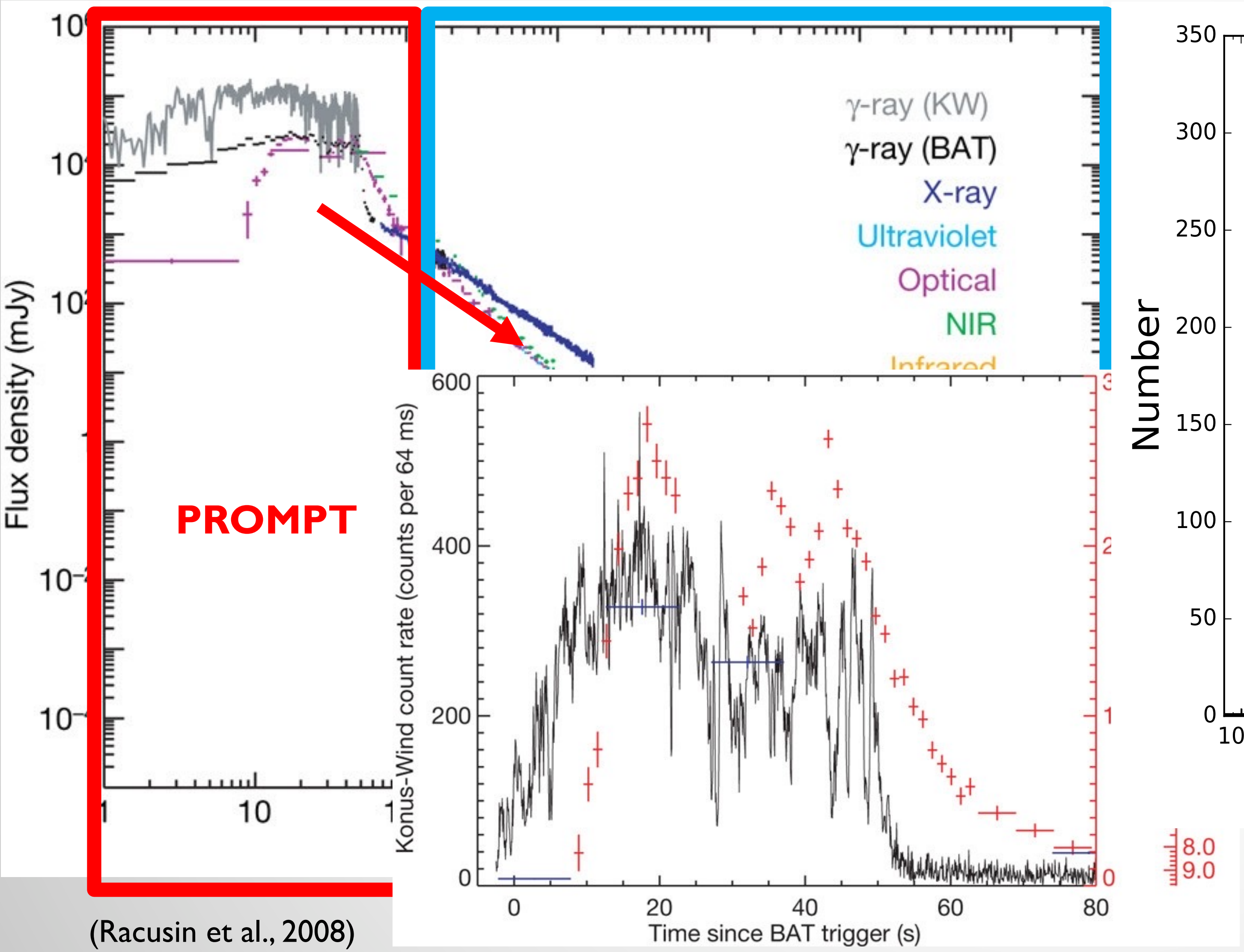
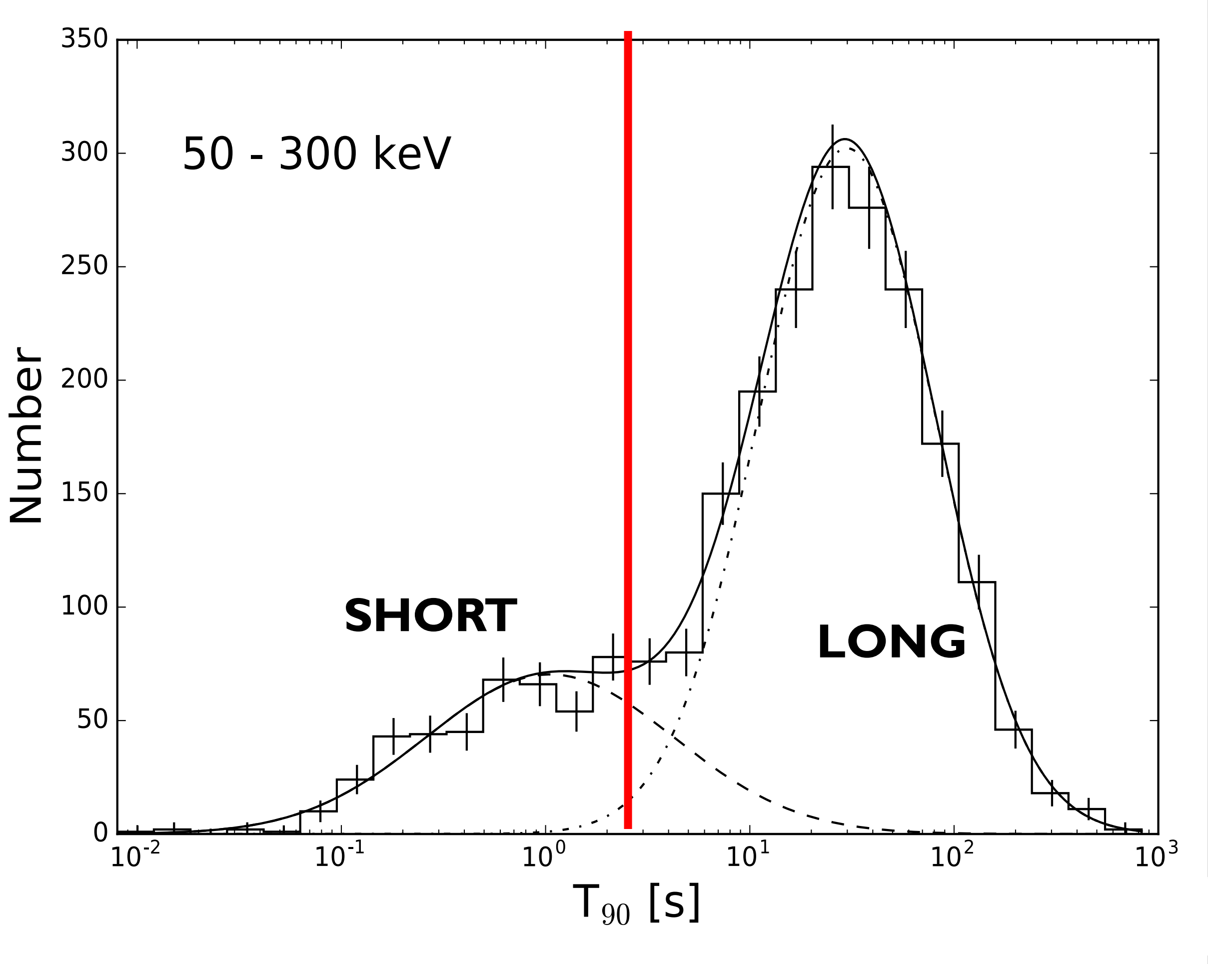


GRB130427A (Ackermann et al., 2013)

Prompt phase

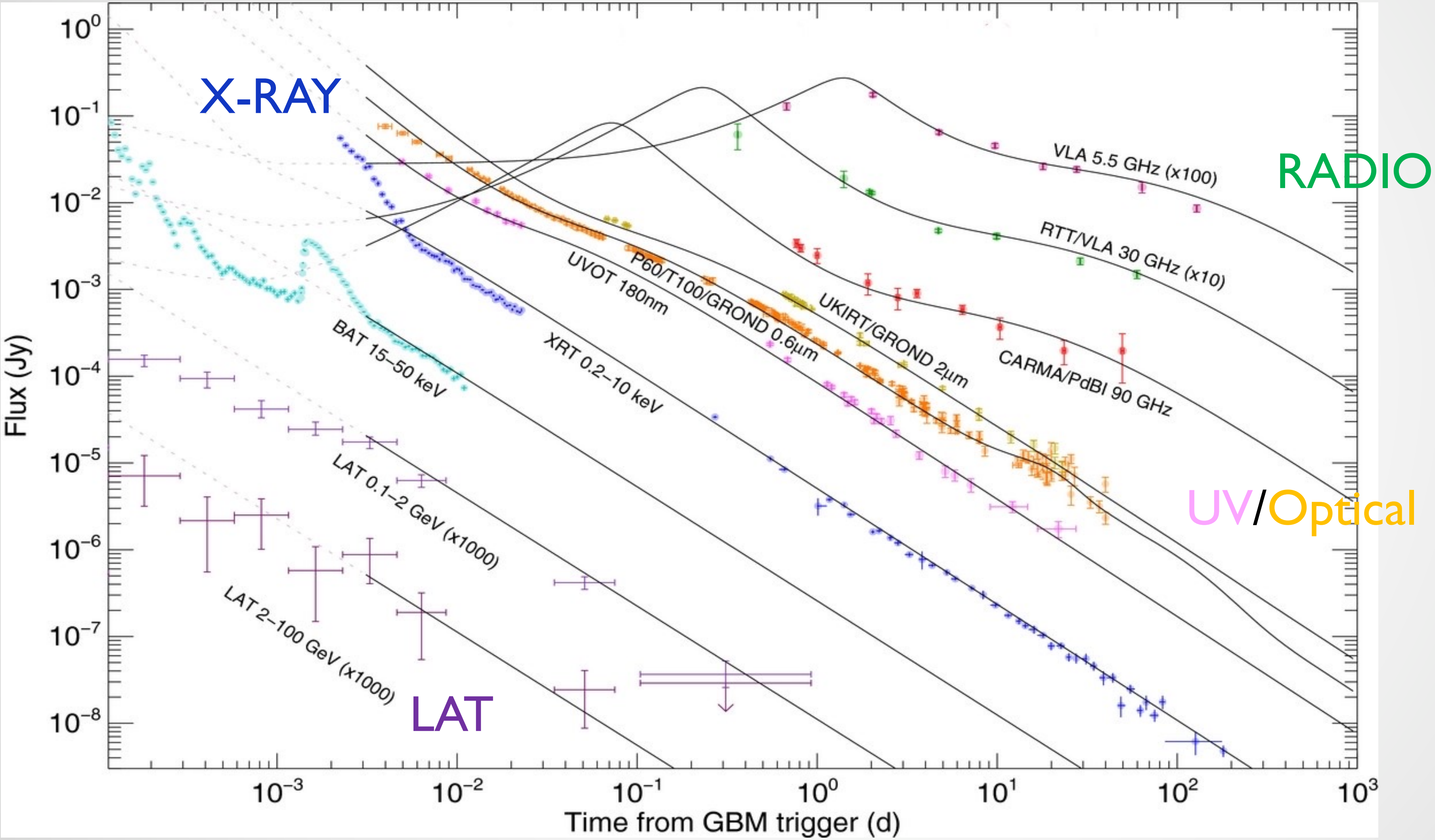


(Racusin et al., 2008)



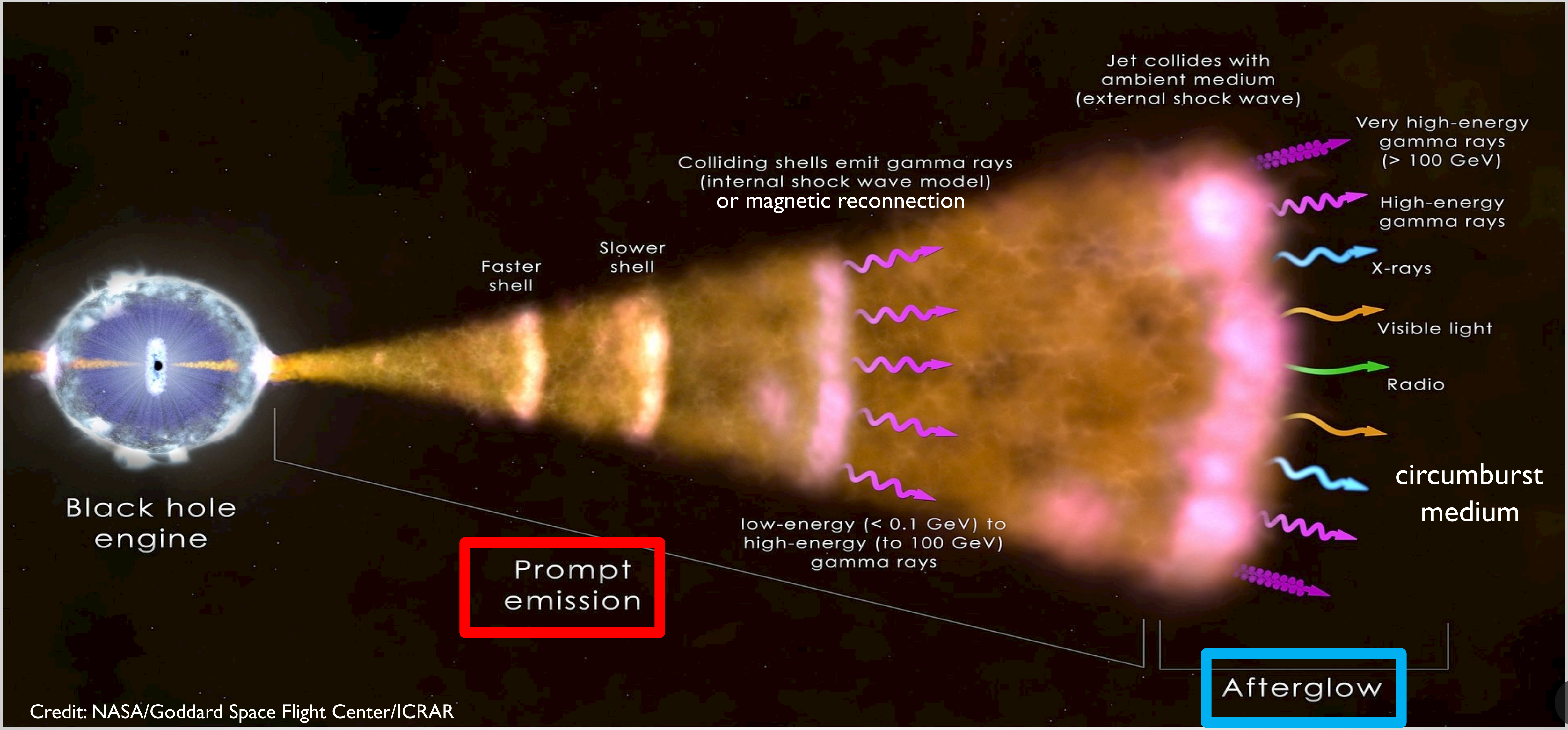
(von Kienlin et al., 2020)

Afterglow phase



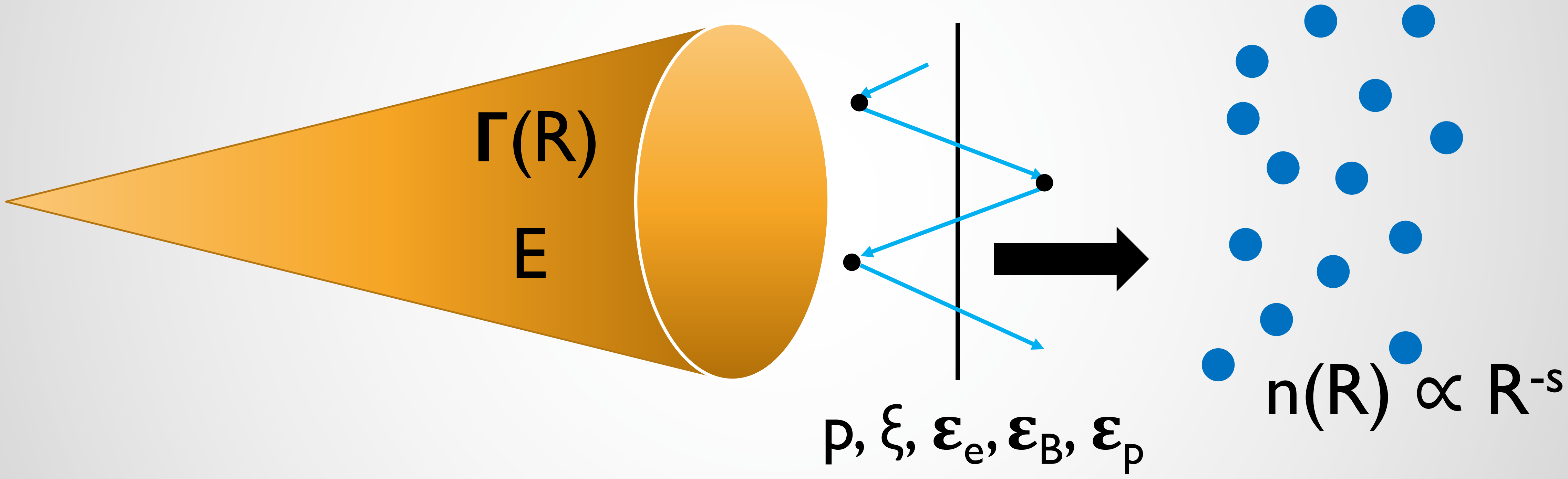
GRB130427A (Perleay et al., 2014)

GRB Standard Model



Afterglow: the external forward shock scenario

Decelerating blastwave interacting with the circumburst external medium



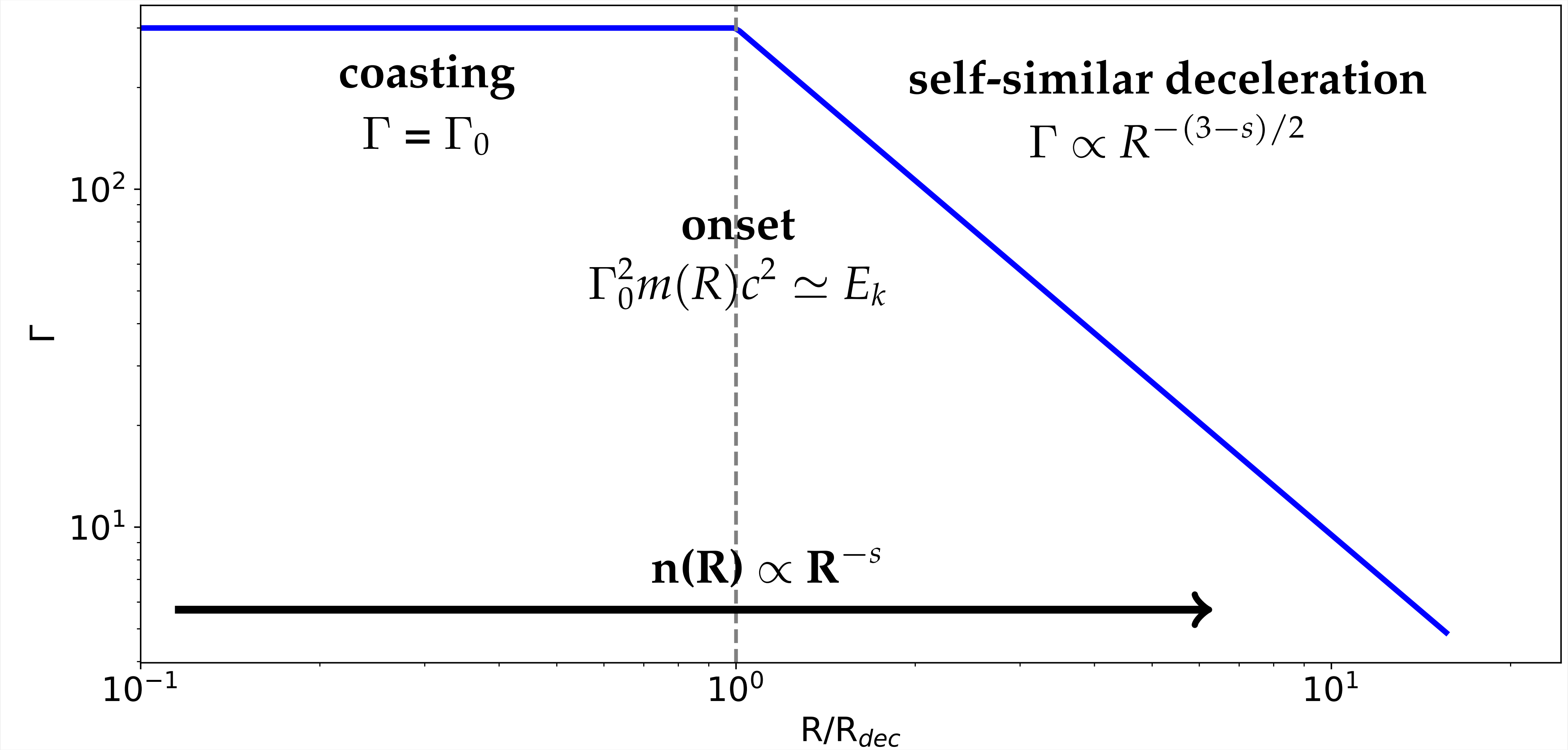
Jet dynamics

Relativistic shock acceleration

External circumburst medium

Afterglow: the external forward shock scenario

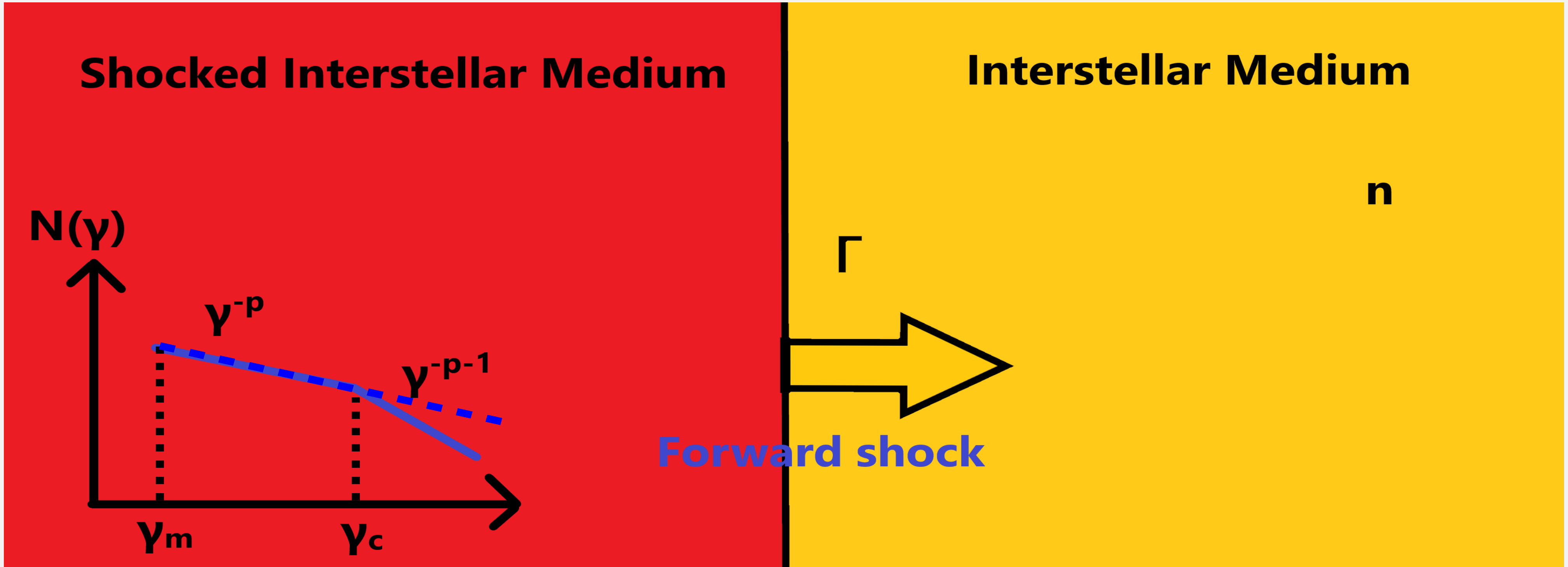
Jet dynamics



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

Afterglow: the external forward shock scenario

Relativistic shocks in GRB afterglow



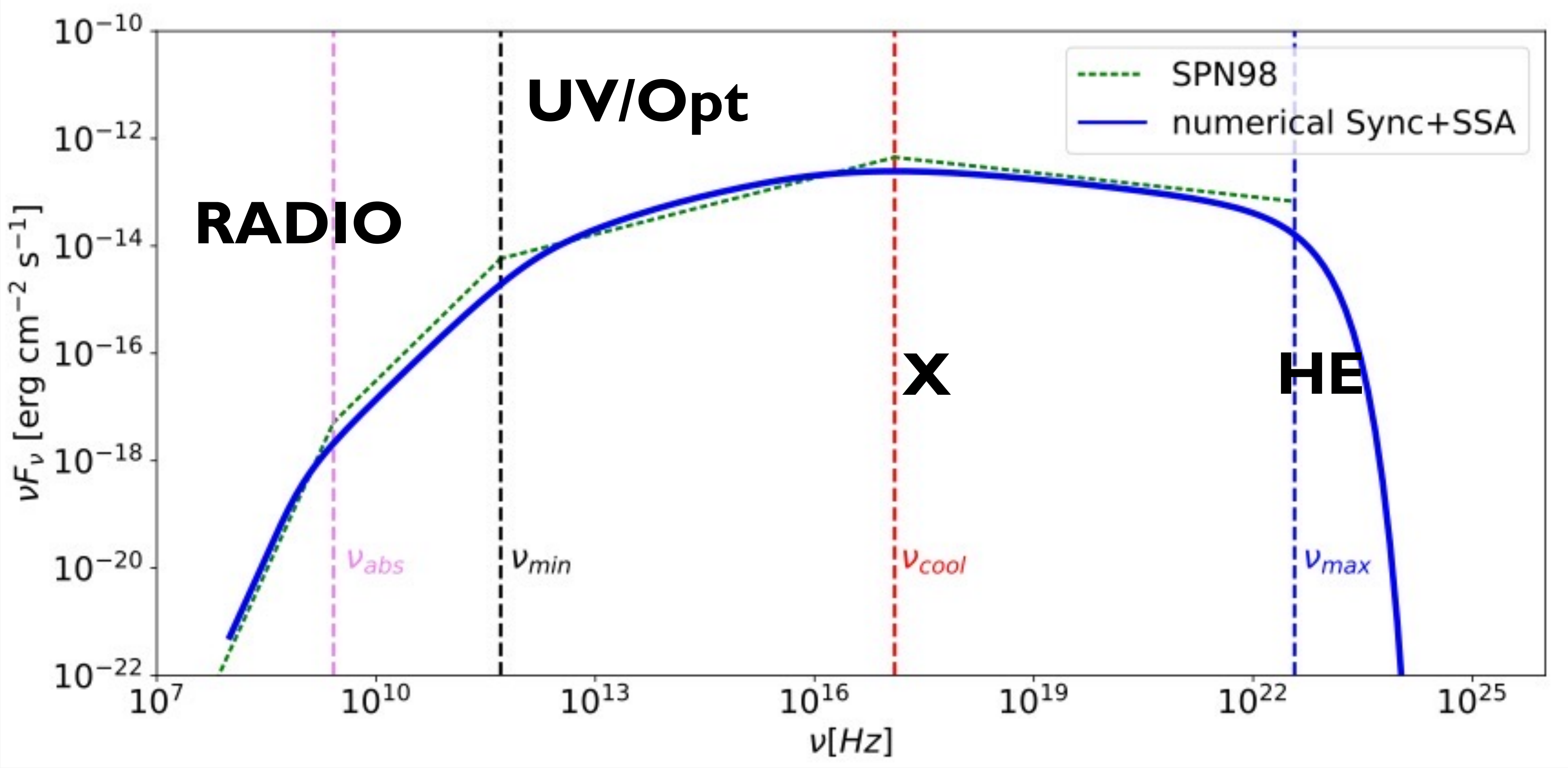
$u' = (\Gamma - 1)n' m_p c^2 \quad u'_e = \xi \langle\gamma\rangle m_e c^2 n'$

$u'_e = \varepsilon_e u' \quad u'_P = \varepsilon_P u'$

$u'_B = \varepsilon_B u' = B^2/8\pi$

Afterglow: the external forward shock scenario

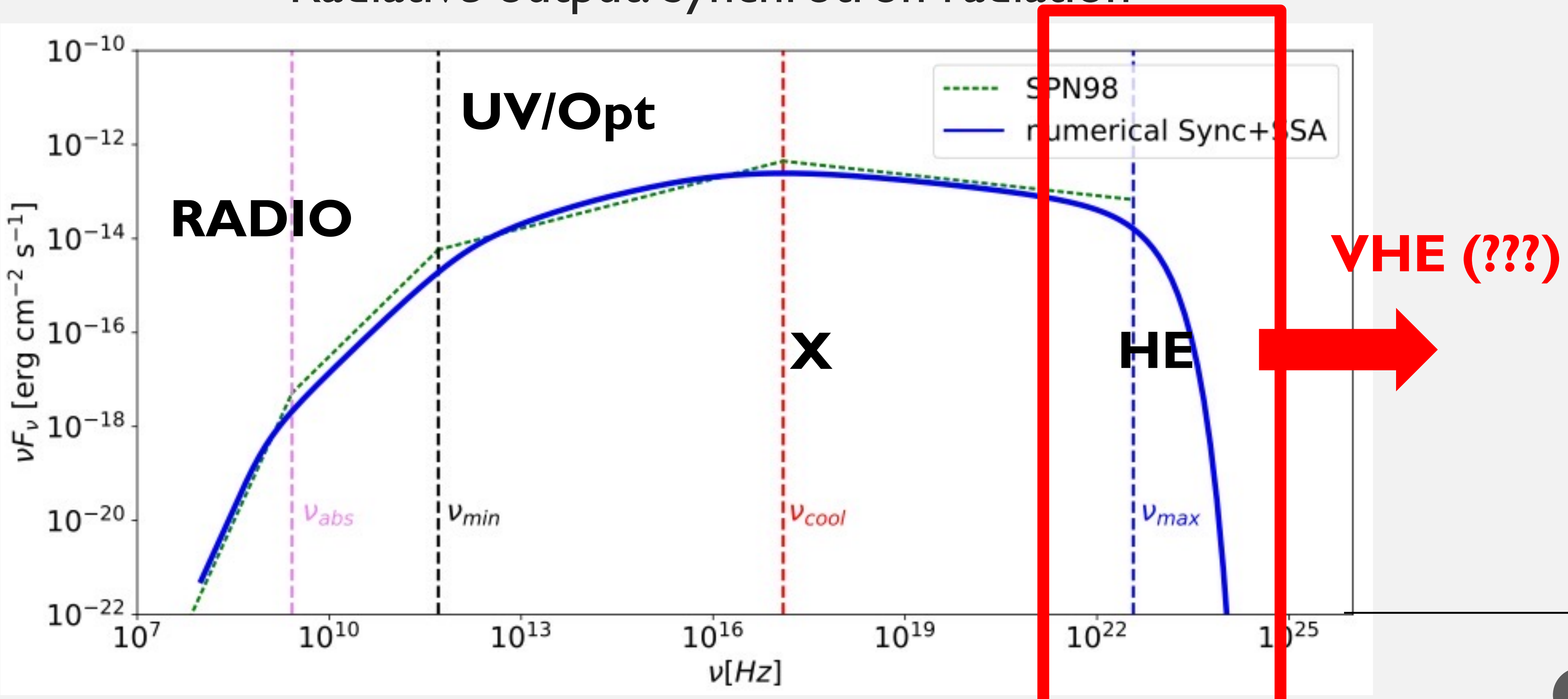
Radiative output: Synchrotron radiation



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

Afterglow: the external forward shock scenario

Radiative output: Synchrotron radiation

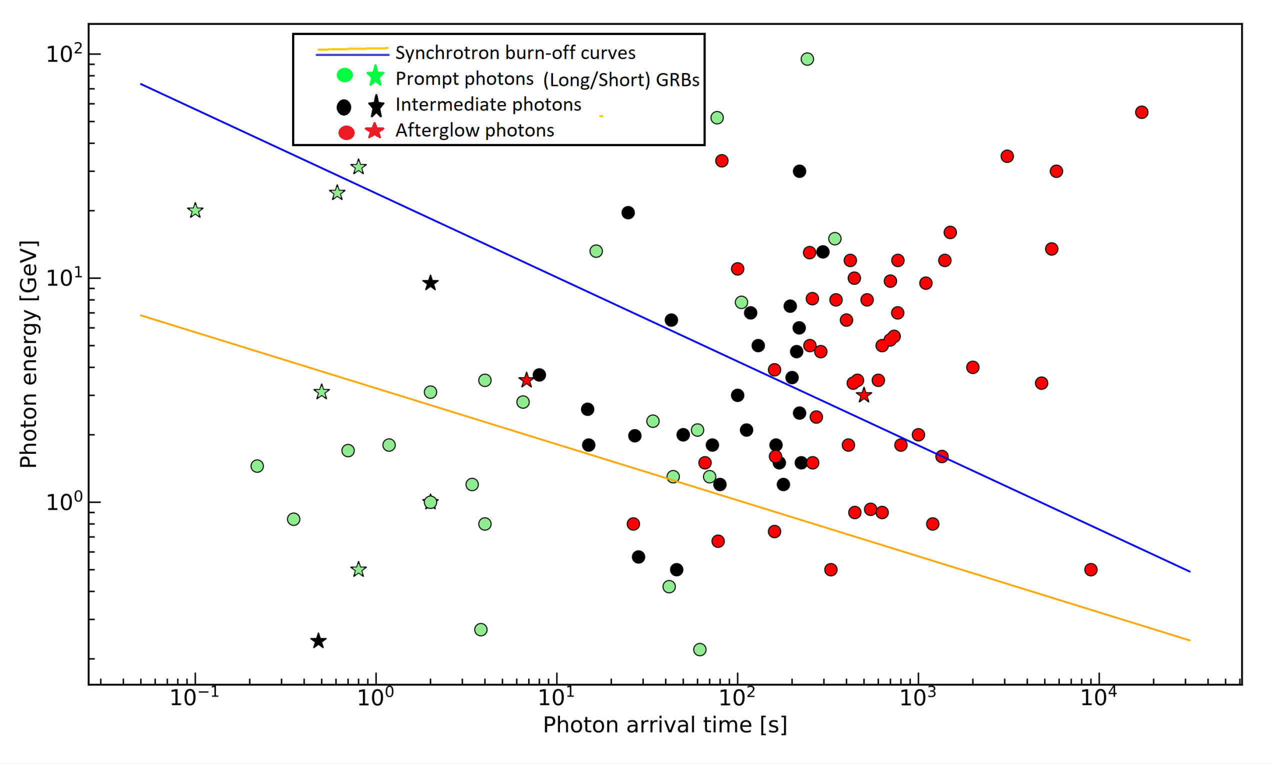


See Sari et al, 1998; Panaitescu et al. 2000; Granot et al. 2002

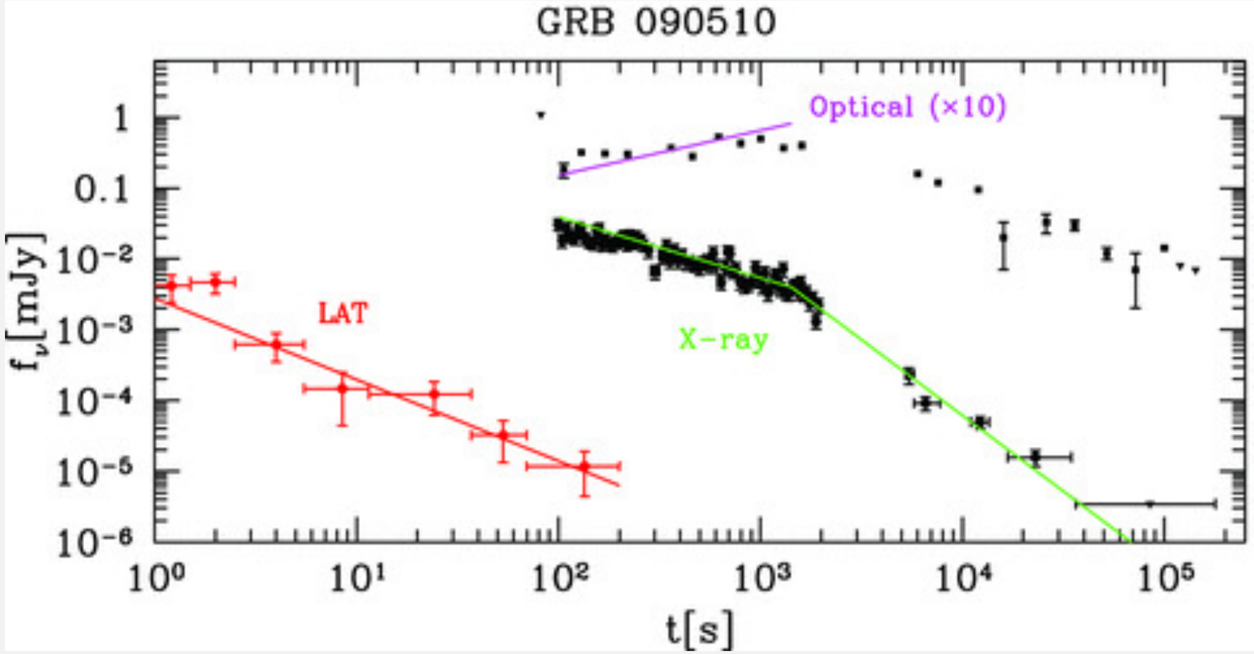
Open Issue: the HE and VHE radiation

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

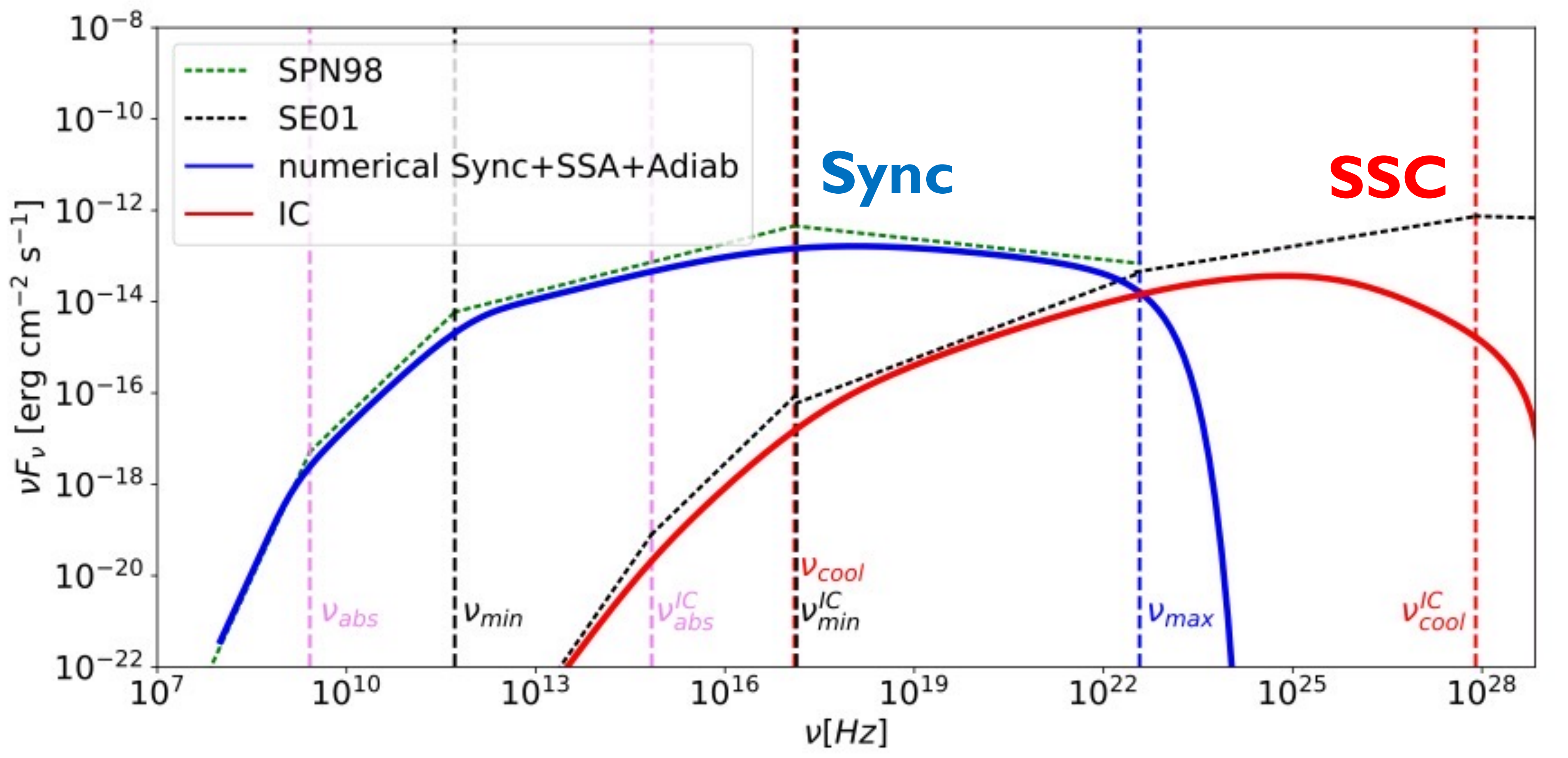
- Synchrotron emission from e^- → Limited by burnoff limit, microphysics conditions, particle acceleration assumptions

- 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

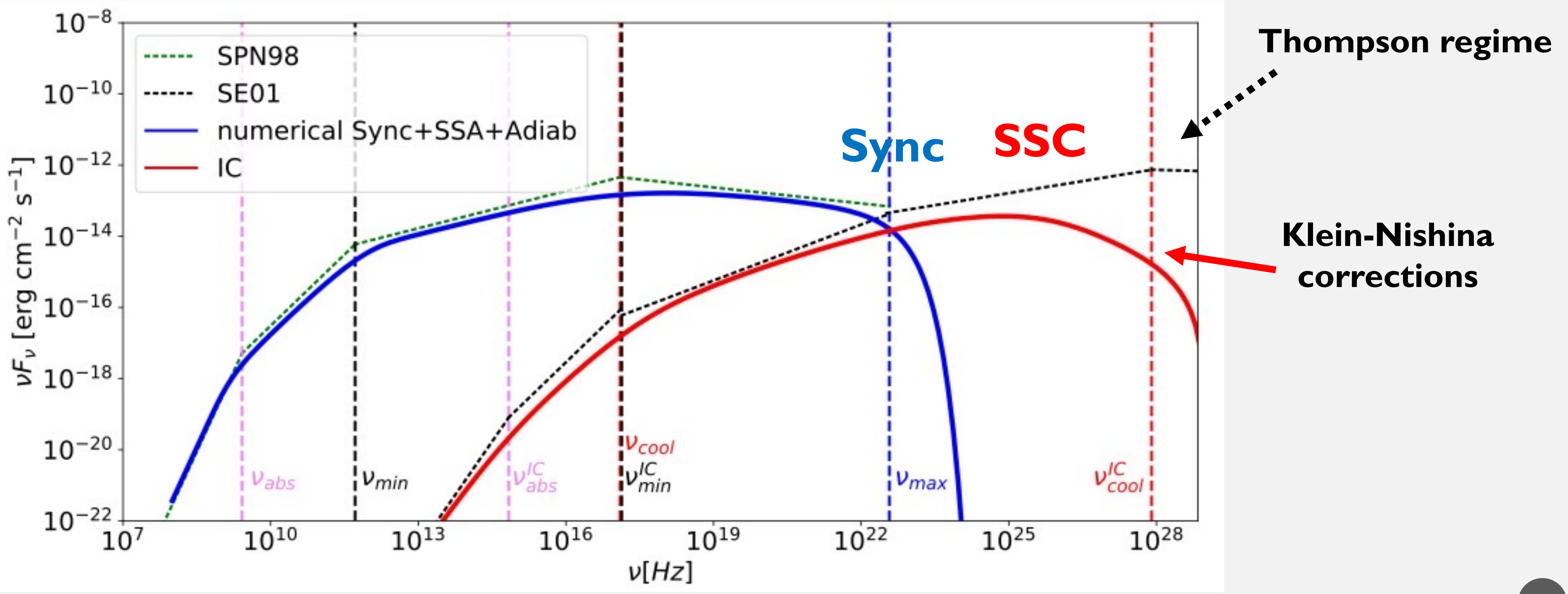
VHE emission



Miceli & Nava, 2022

VHE emission: KN corrections

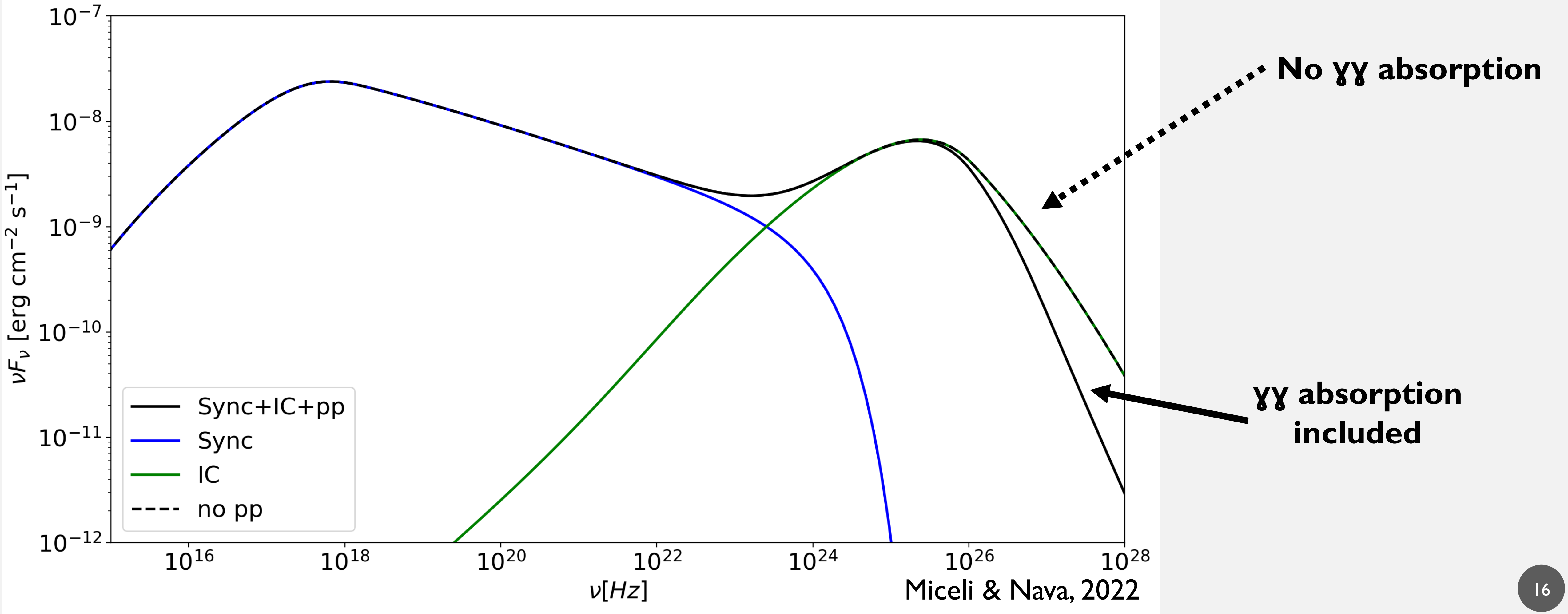
Shaping the VHE spectrum



Miceli & Nava, 2022

VHE emission: ɣɣ absorption

Shaping the VHE spectrum



VHE emission

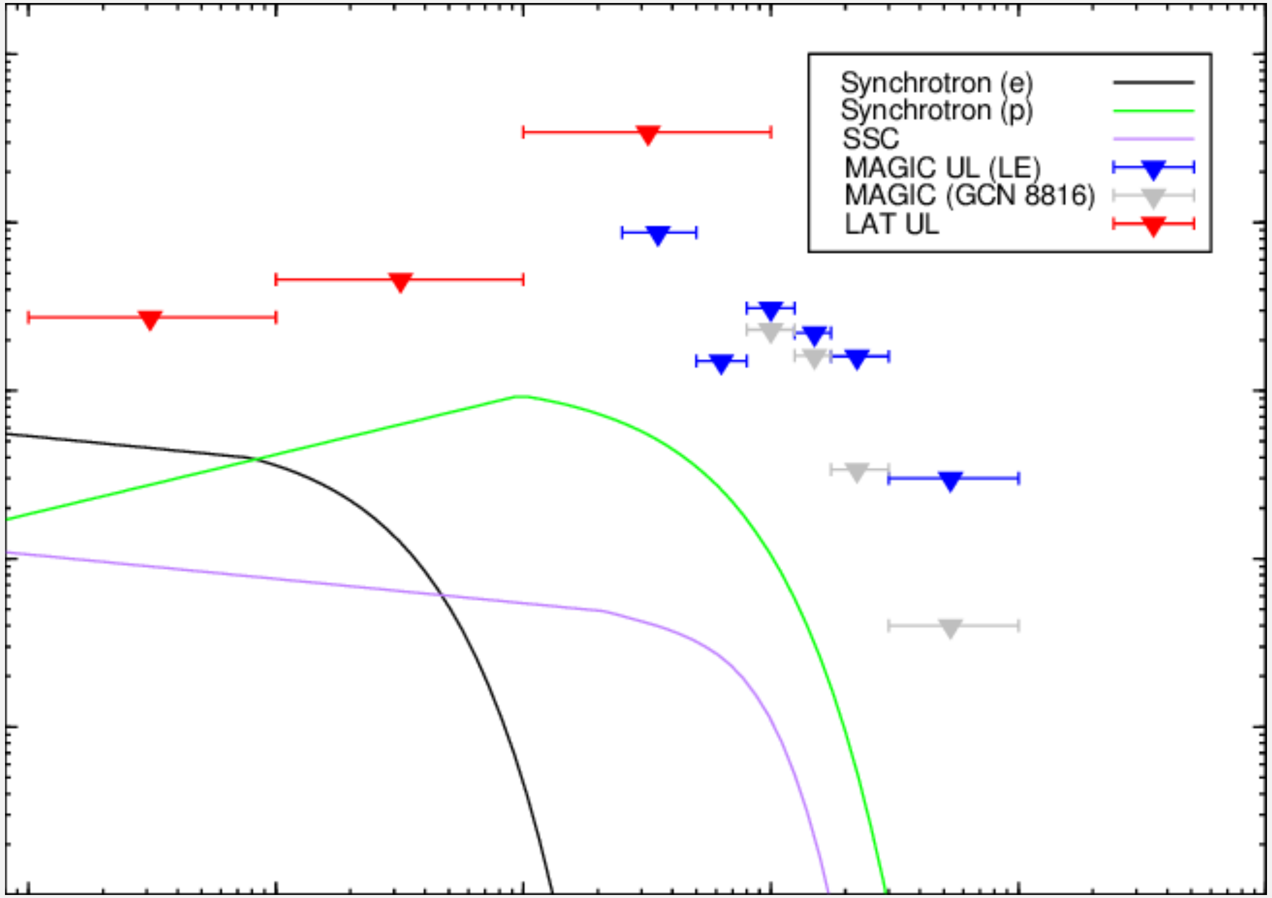
Afterglow open issues

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

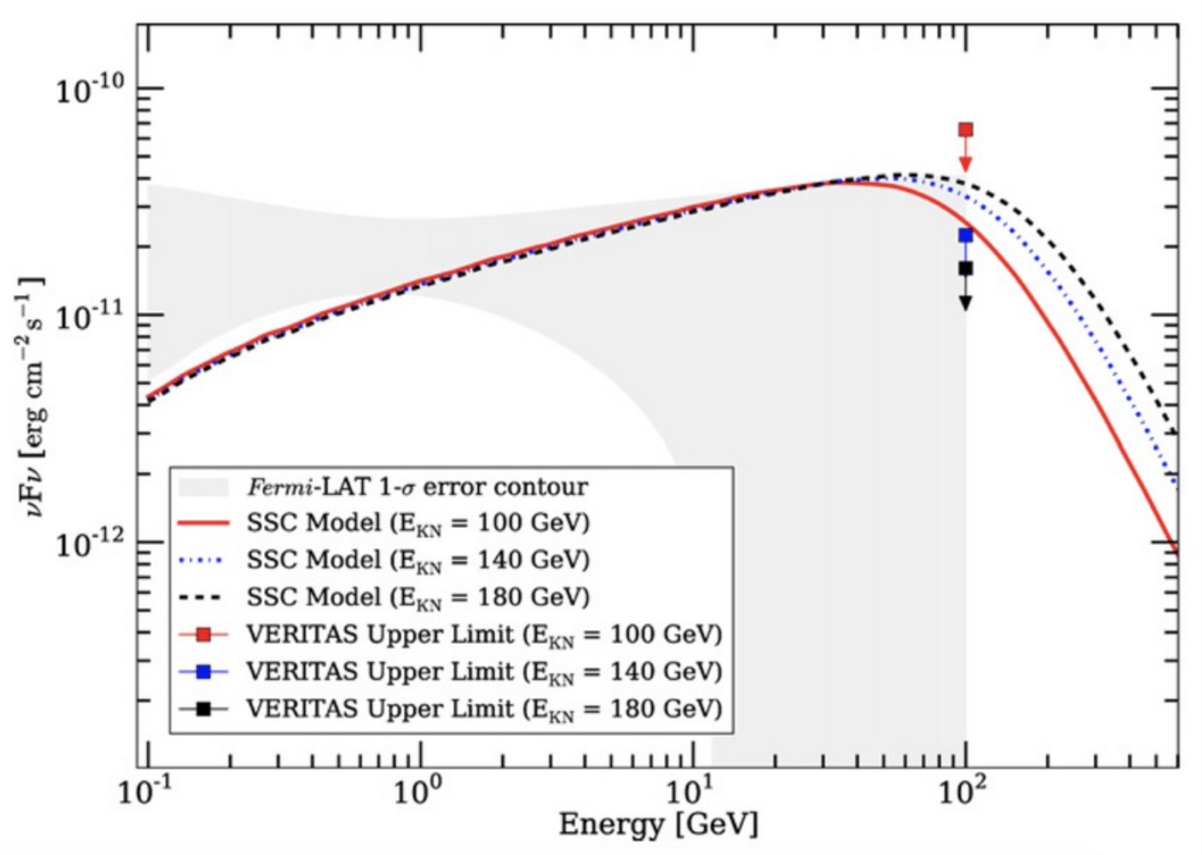
VHE detection can provide renovate and boost afterglow studies

VHE emission

Cherenkov telescope observations: only upper limits until 2019



Aleksic et al. 2014



Aliu et al., 2014

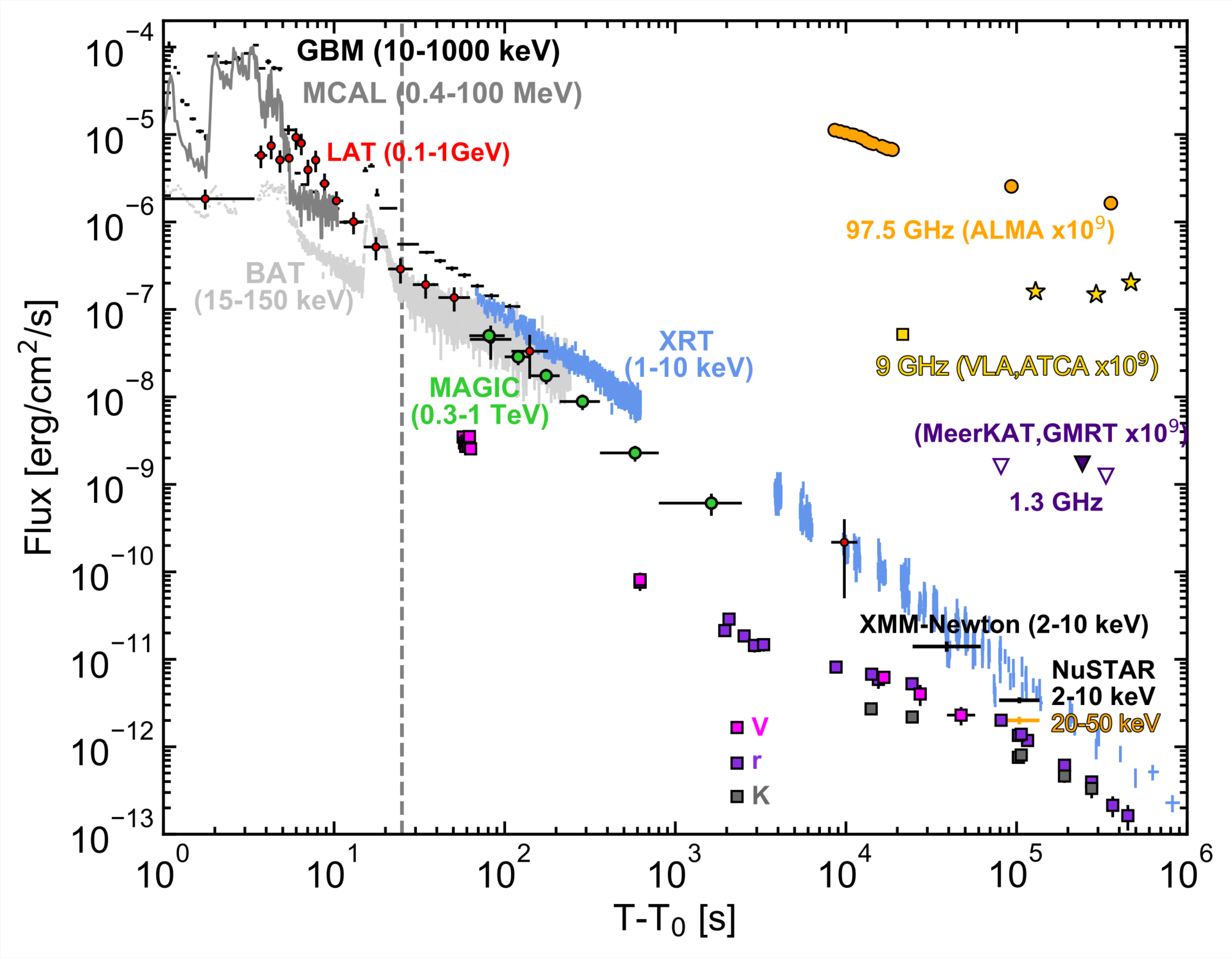
MODELING OF TeV EMISSION

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

GRB190114C

X-ray + GeV + TeV

↓

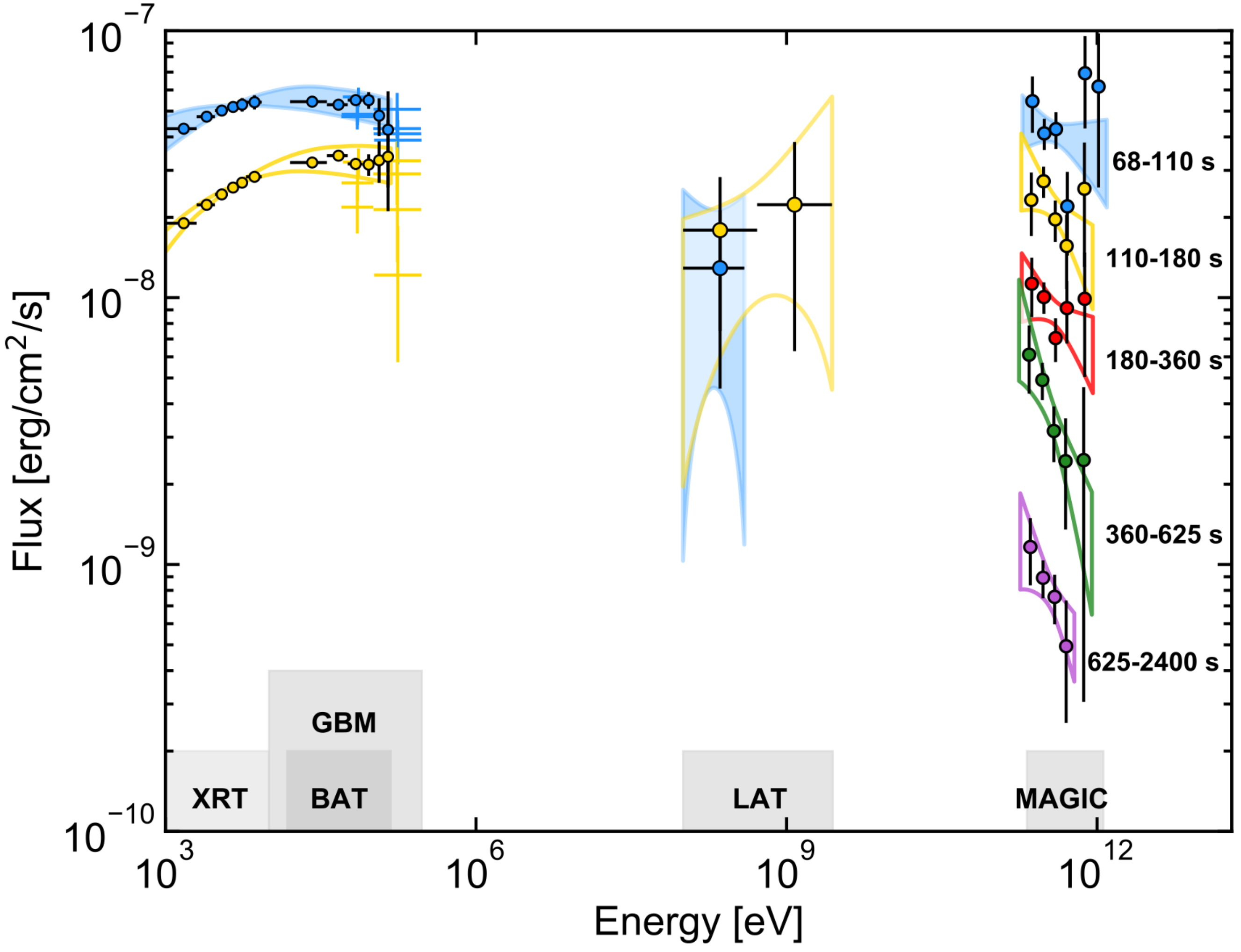
Spectral hardening for E > 0.2 TeV

↓

Can’t be extention of Synchrotron component

↓

New emission component at VHE



MAGIC Coll. et al., 2019

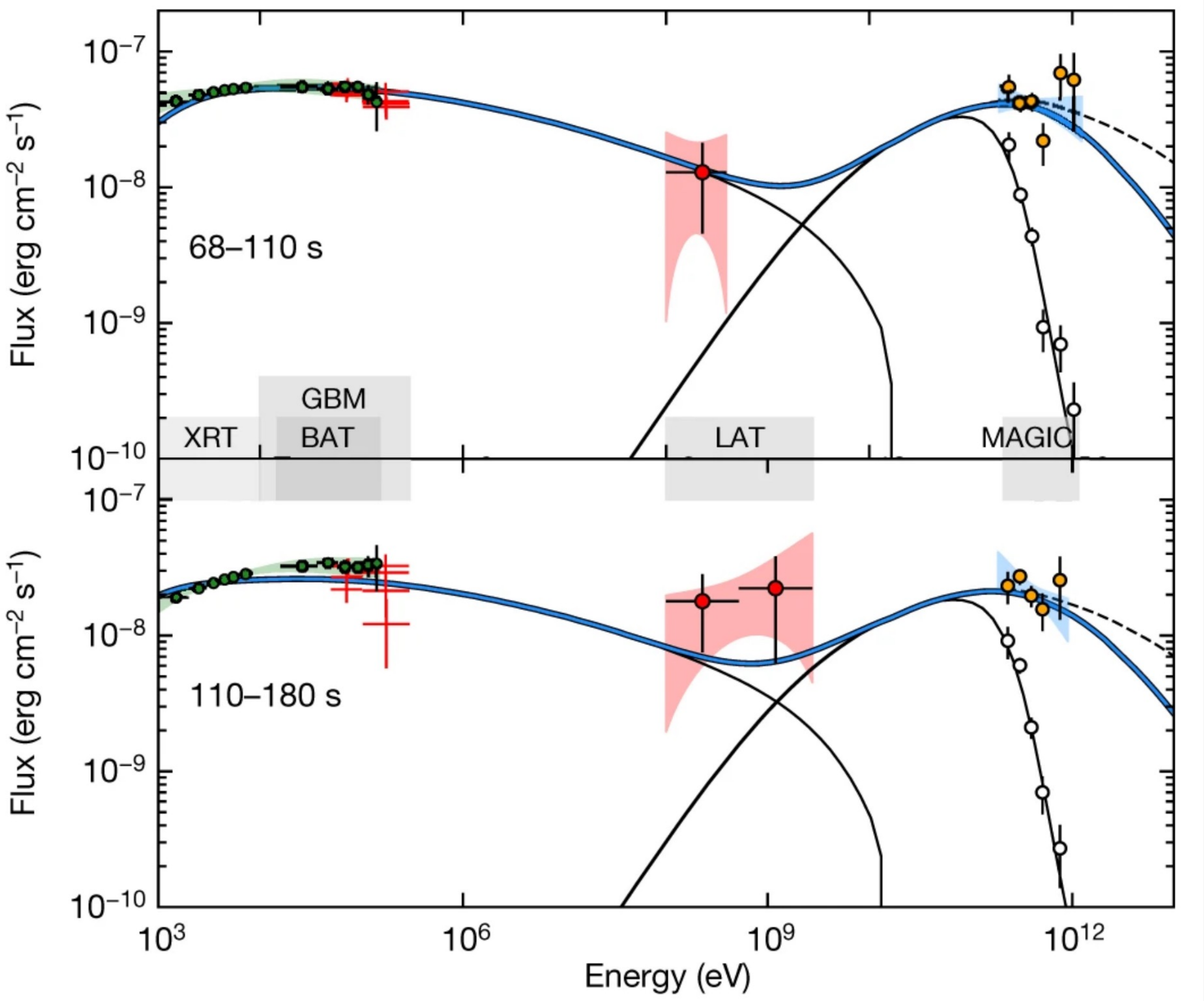
Modeling of GRB190114C

Observed
No γ-γ opacity
EBL-deabsorbed

MAGIC soft spectrum:

- Klein-Nishina
- γ-γ internal absorption

GRB afterglow parameters:
$E_k \gtrsim 3 \times 10^{53}$ erg
$\varepsilon_e \approx 0.05\text{-}0.15$
$\varepsilon_b \approx 0.05\text{-}1 \times 10^{-3}$
$n \approx 0.5\text{-}5\ \mathrm{cm}^{-3}$
$p \approx 2.4\text{-}2.6$

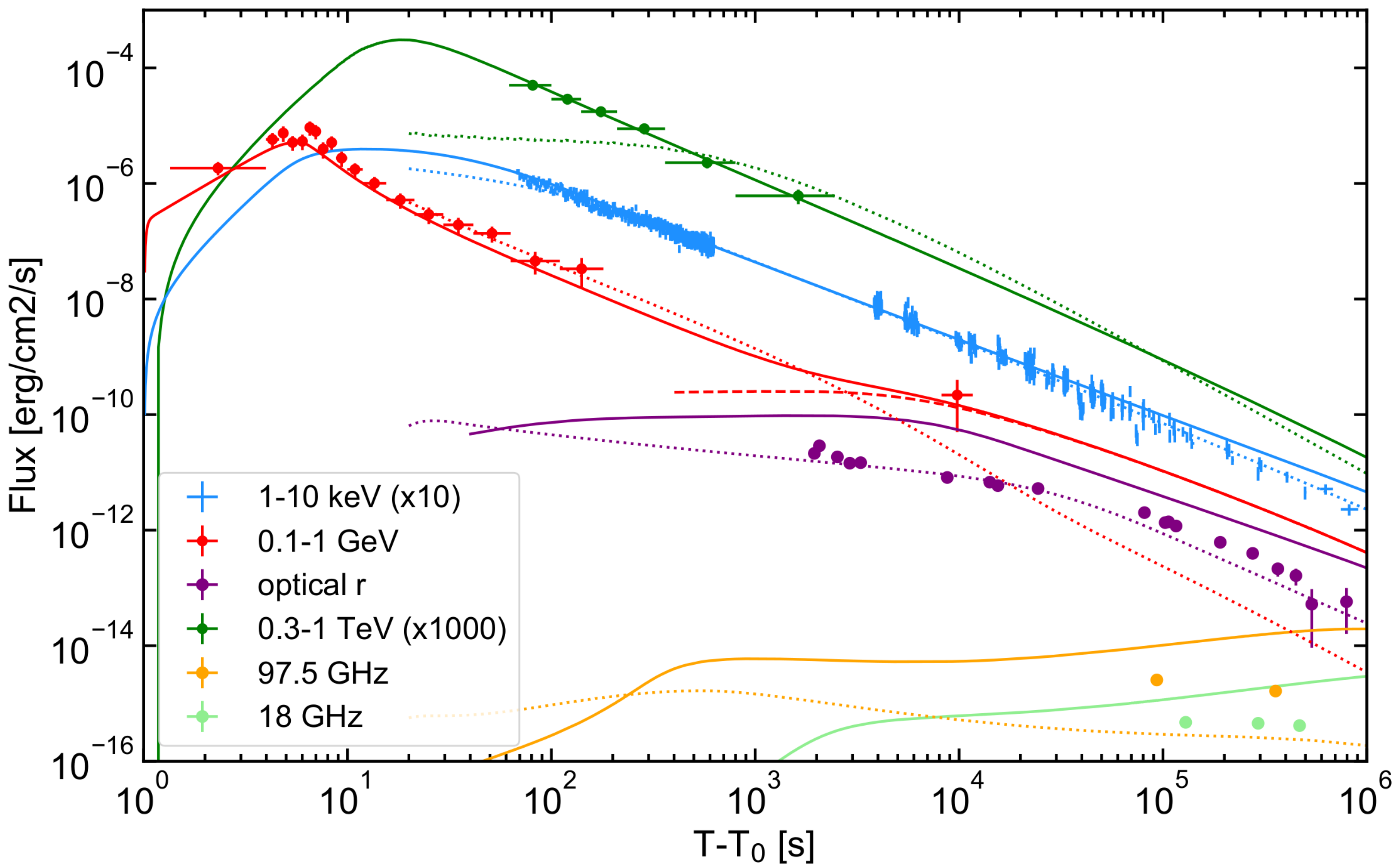


MAGIC Coll. et al., 2019

Modeling of GRB190114C

MWL LIGHT CURVES

- 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



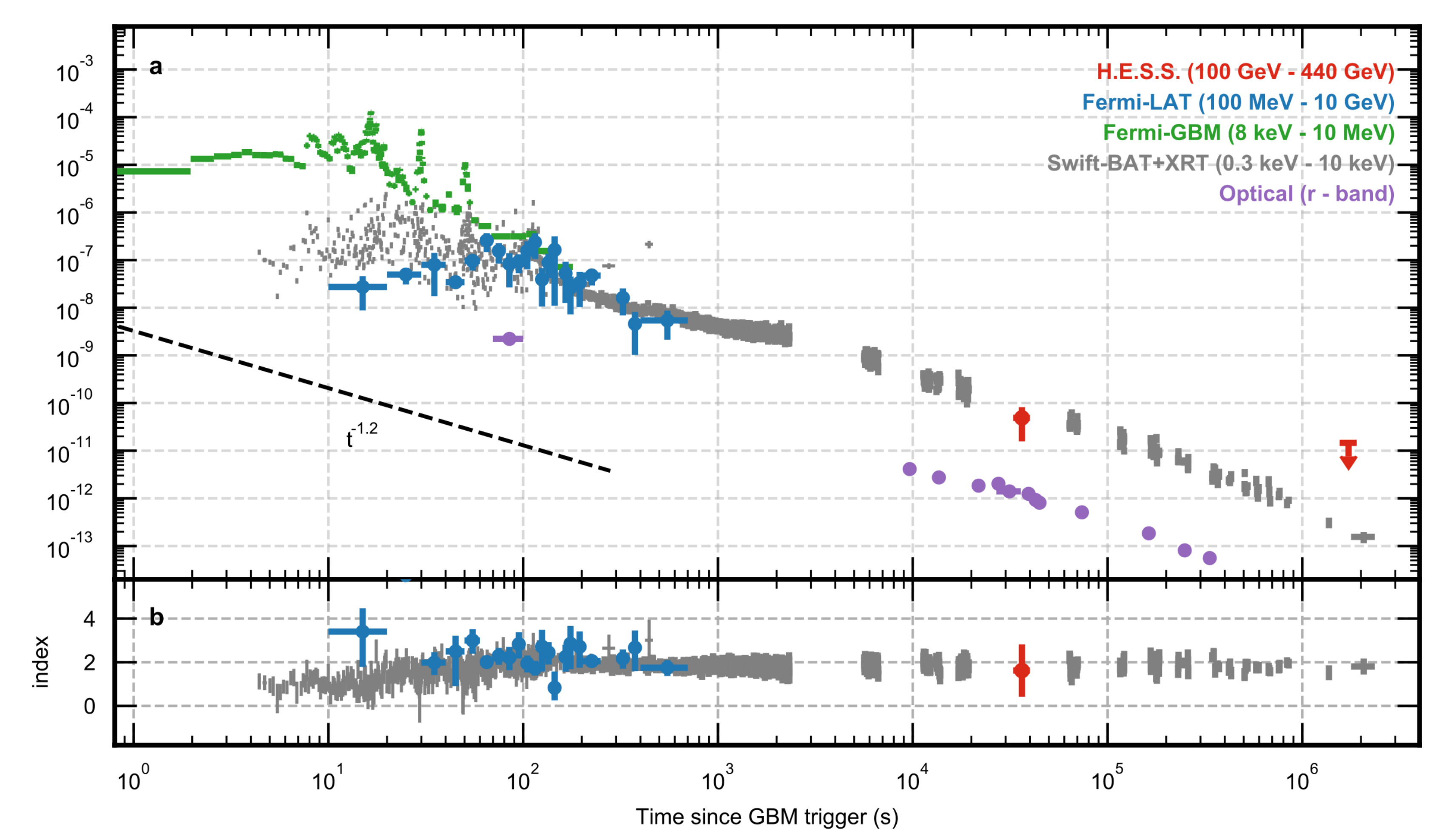
MAGIC Coll. et al., 2019

GRB180720B

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

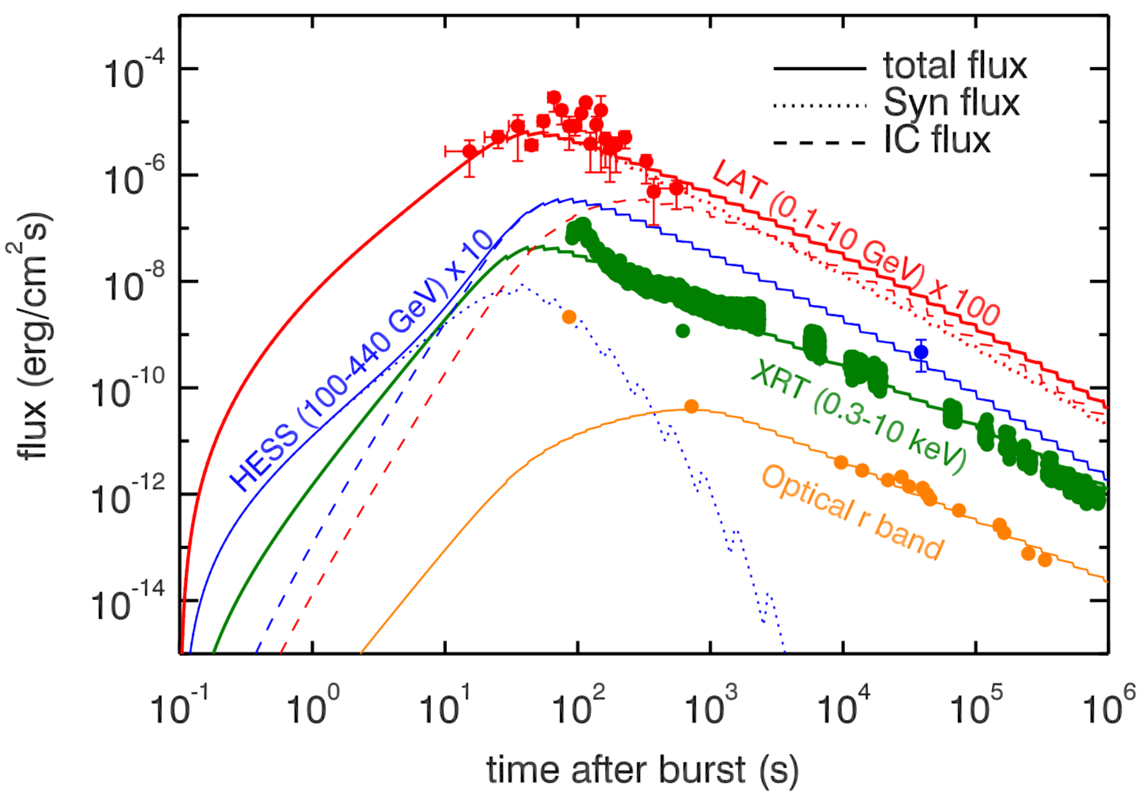
H.E.S.S. detection info:

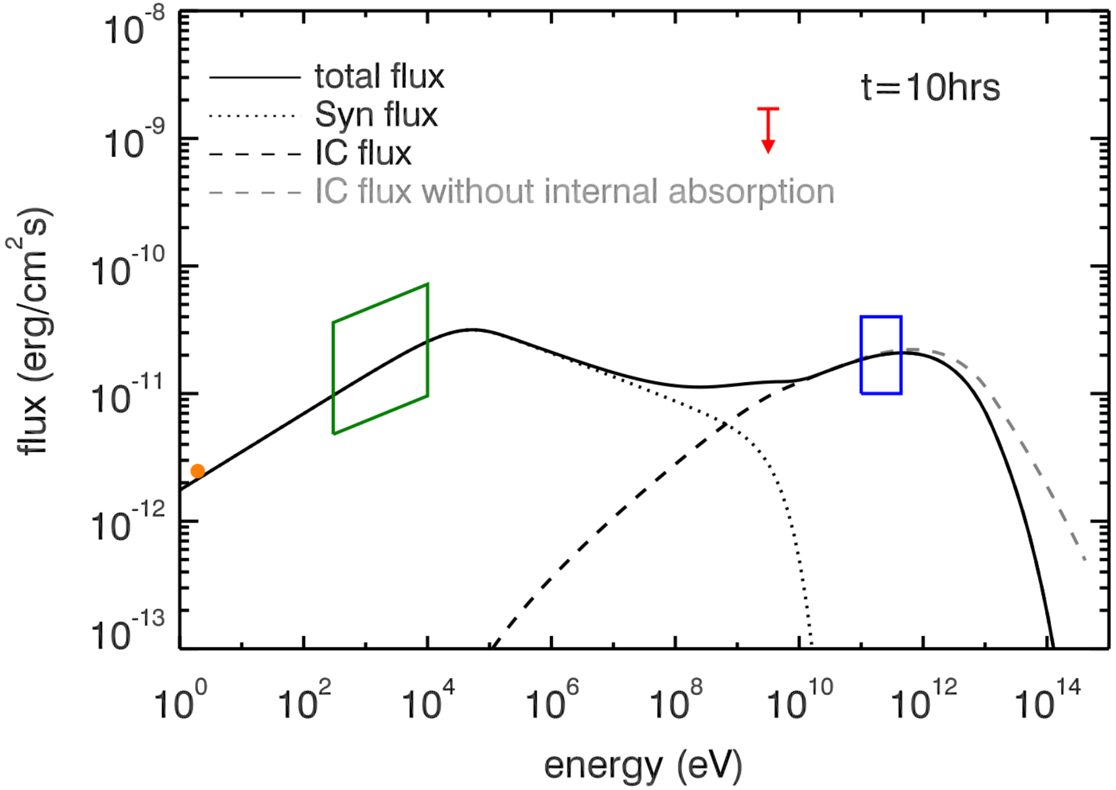
- Tdelay ~ 10 hrs
- > 5.3σ in 2 hrs
- 0.1 – 0.44 TeV energy range



HESS Coll., 2019

Modeling of GRB180720B





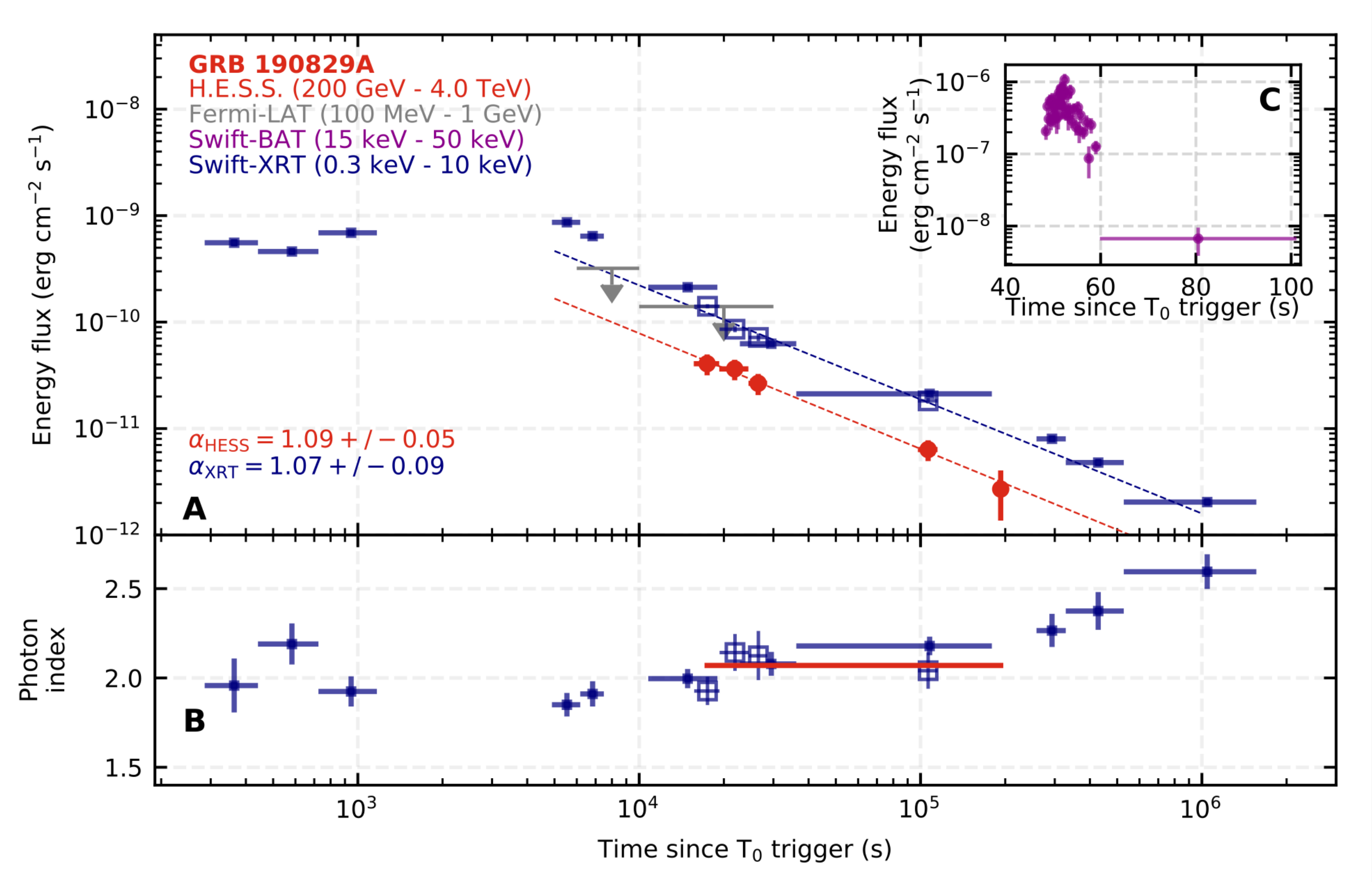
Wang et al.,2019

GRB190829A

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

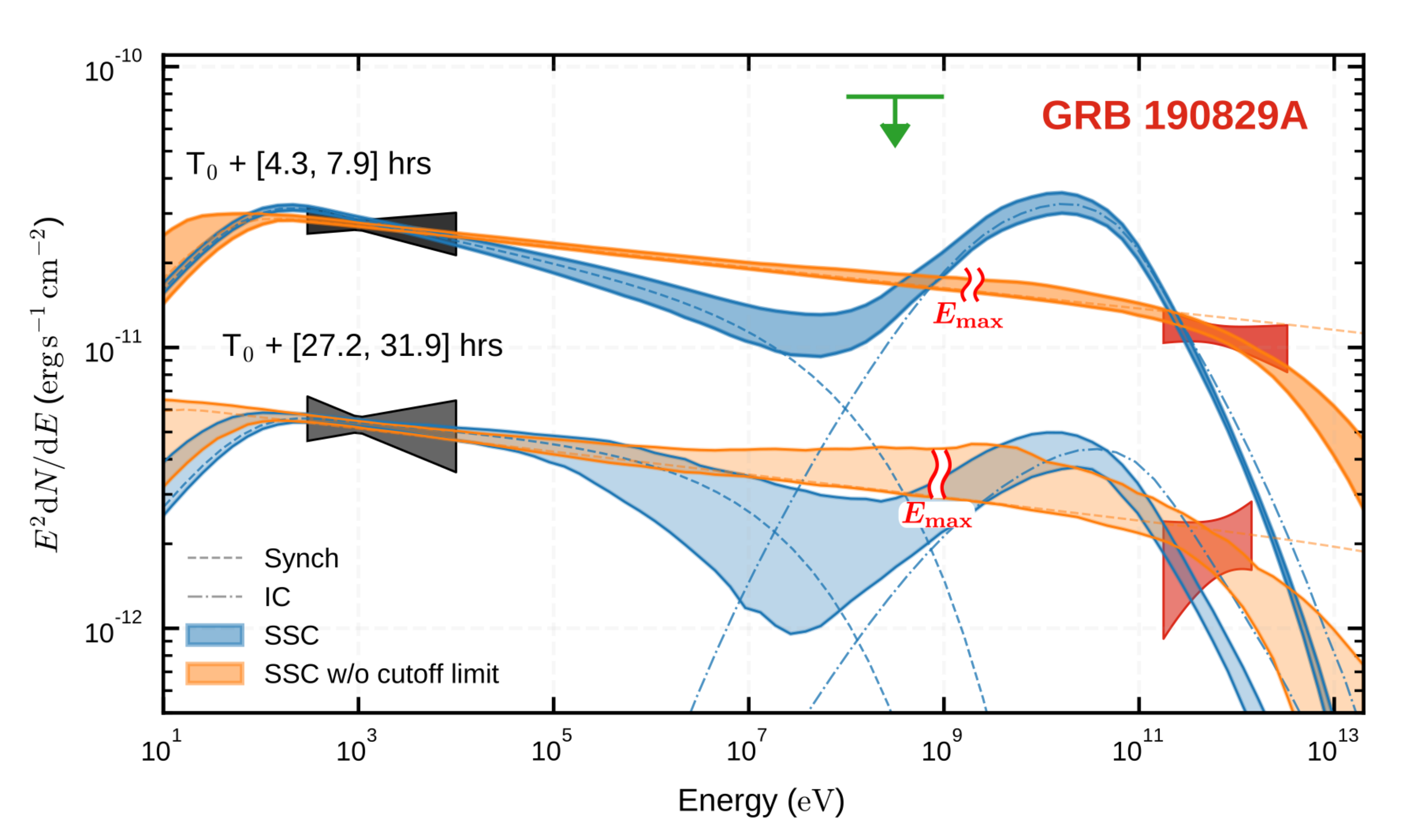
H.E.S.S. detection info:

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



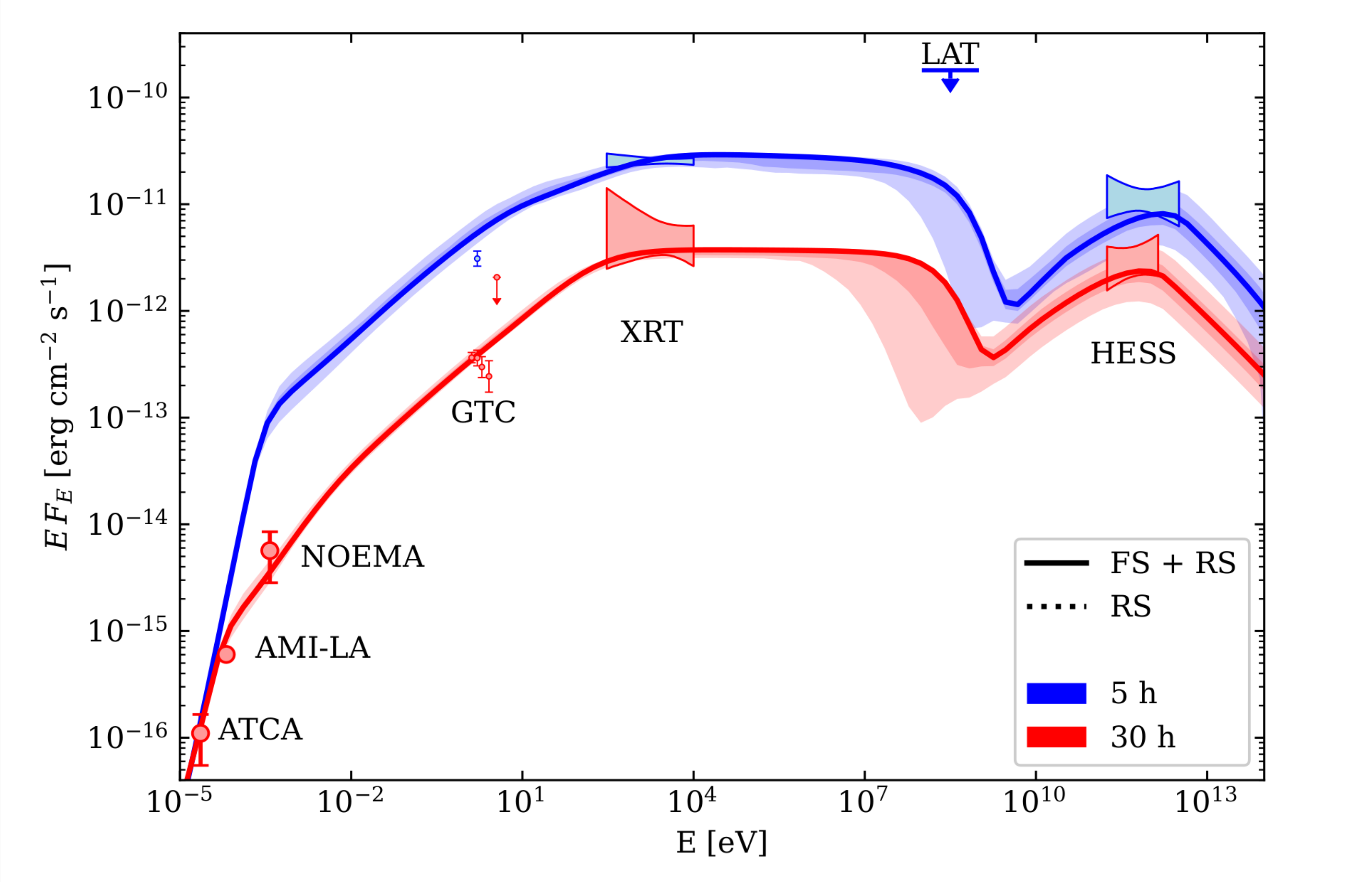
HESS Coll., 2021

Modeling of GRB190829A



HESS Coll., 2021

Modeling of GRB190829A



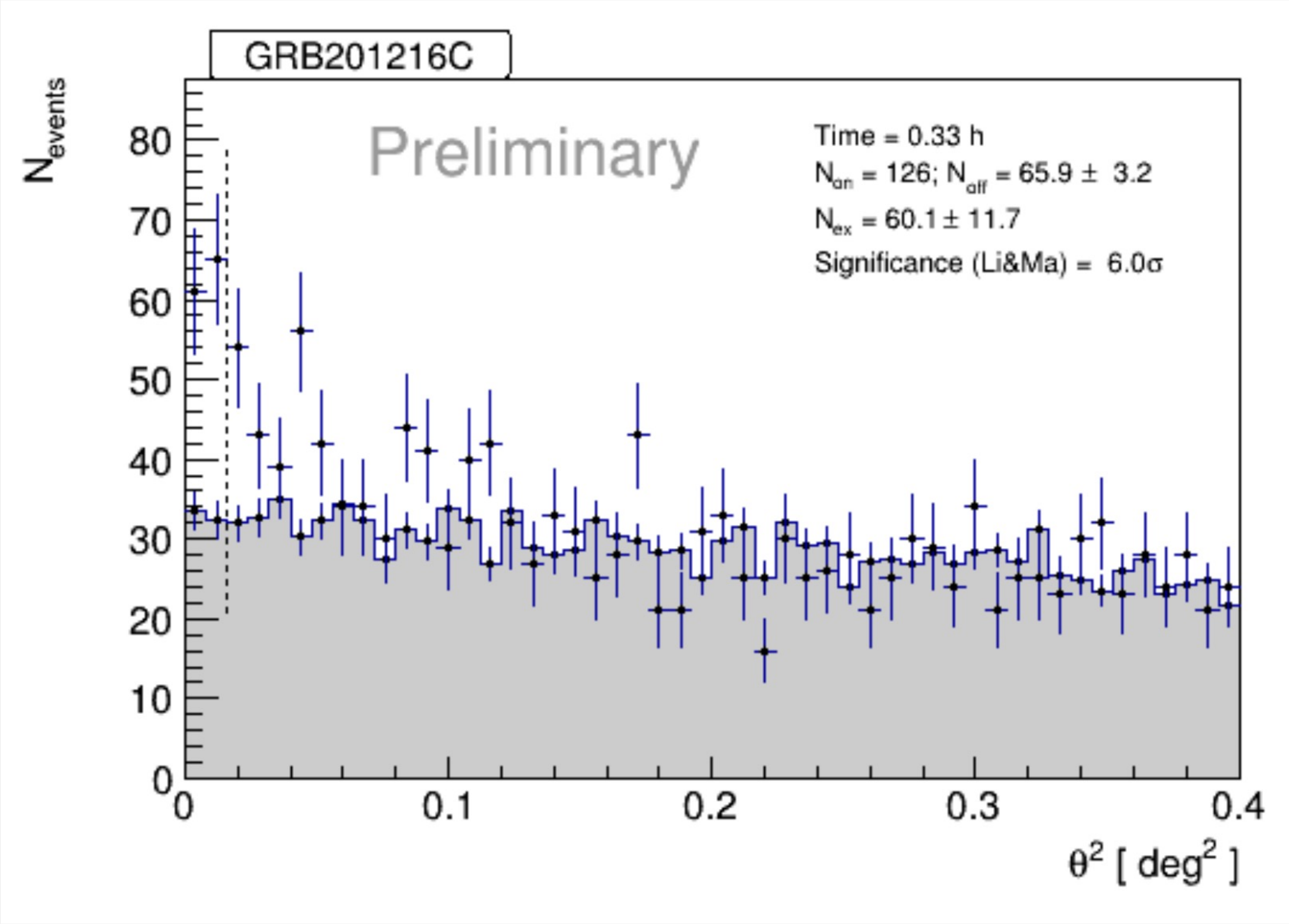
Salafia et al., 2021

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



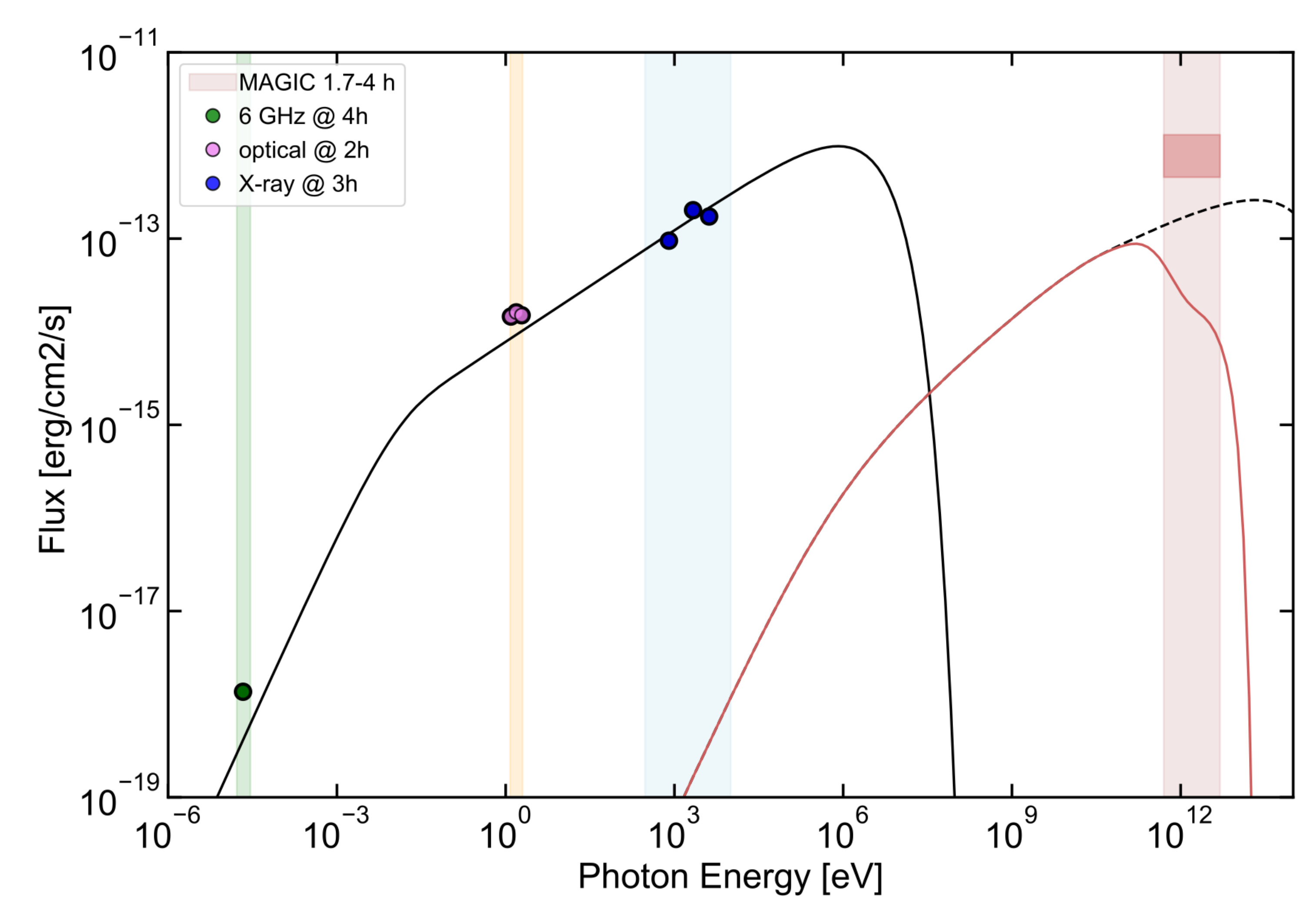
Suda et al., 2021, ICRC

GRB160821B (3σ excess)

- short GRB
- $E_{\gamma,iso} \sim 1.2 \times 10^{49}$ erg
- z = 0.162

MAGIC info:

- Tdelay ~ 24 s
- 3σ in 4 hrs
- 0.5 - 5 TeV energy range
- moon conditions, dedicated analysis



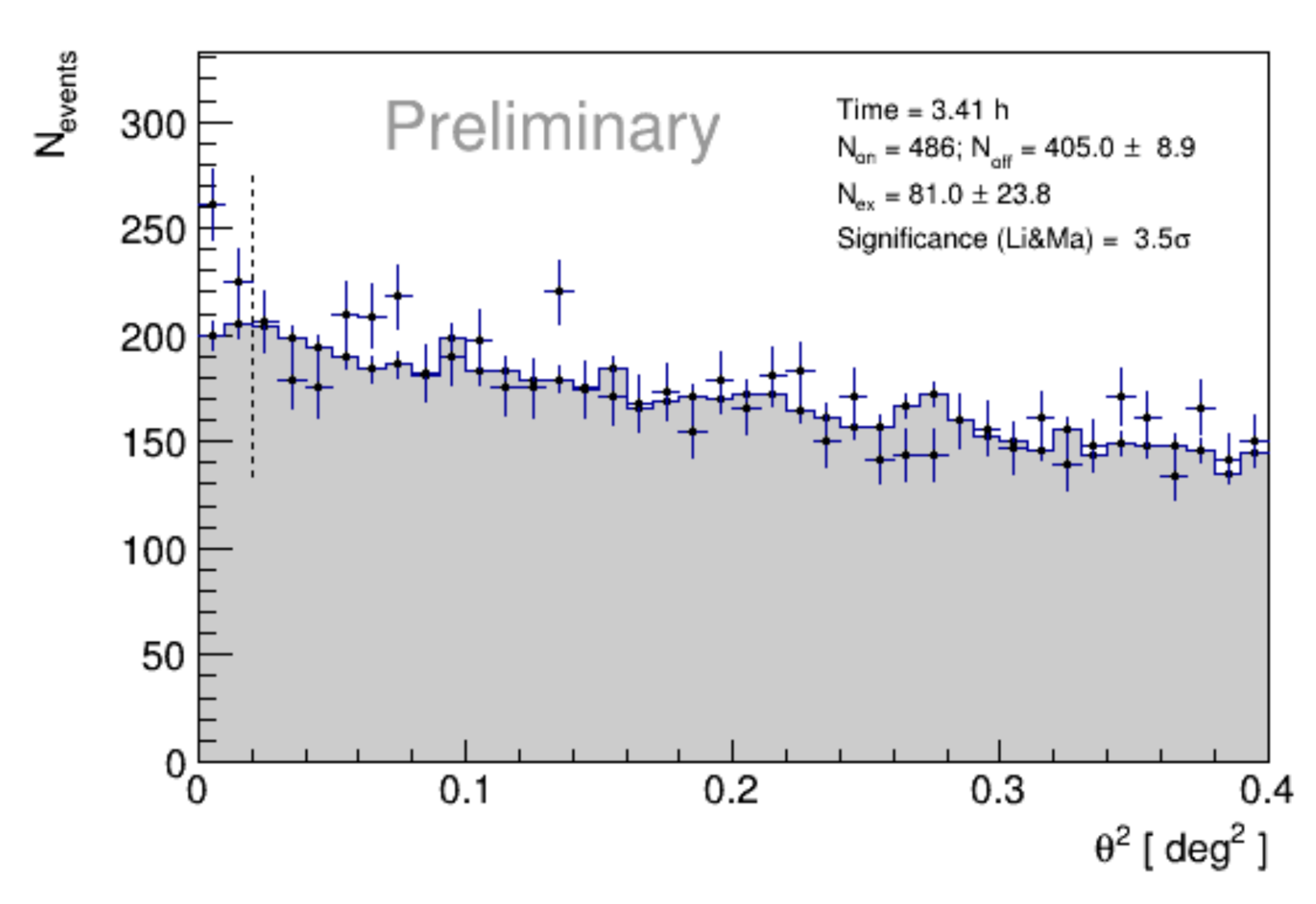
MAGIC Coll., 2021

GRB201015A (>3σ excess)

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

MAGIC info:

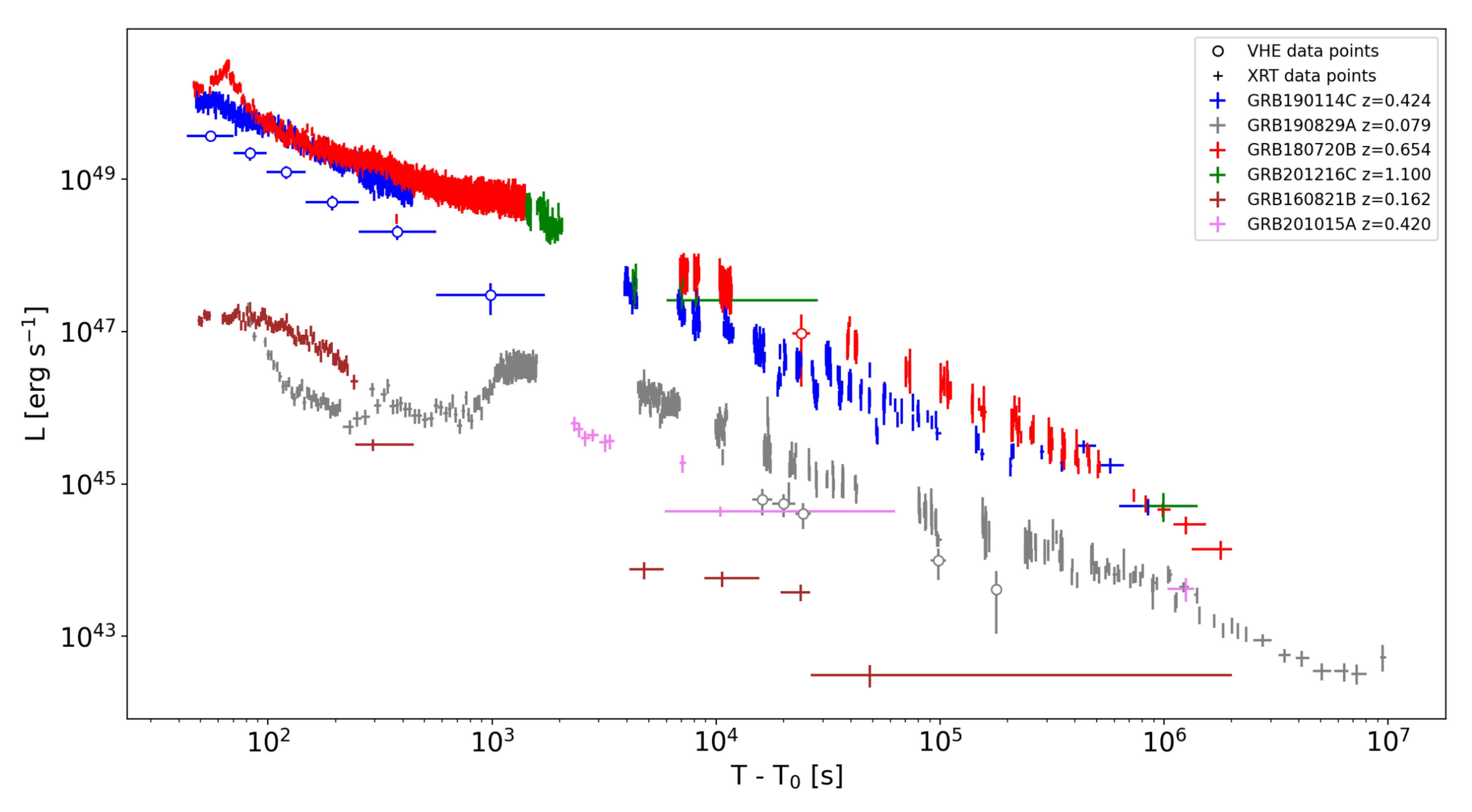
- Tdelay ~ 33 s
- 3.5σ in 3.4 hrs
- 0.14 - ? TeV energy range



Fukami et al., 2021, ICRC

Population of GRBs at VHE

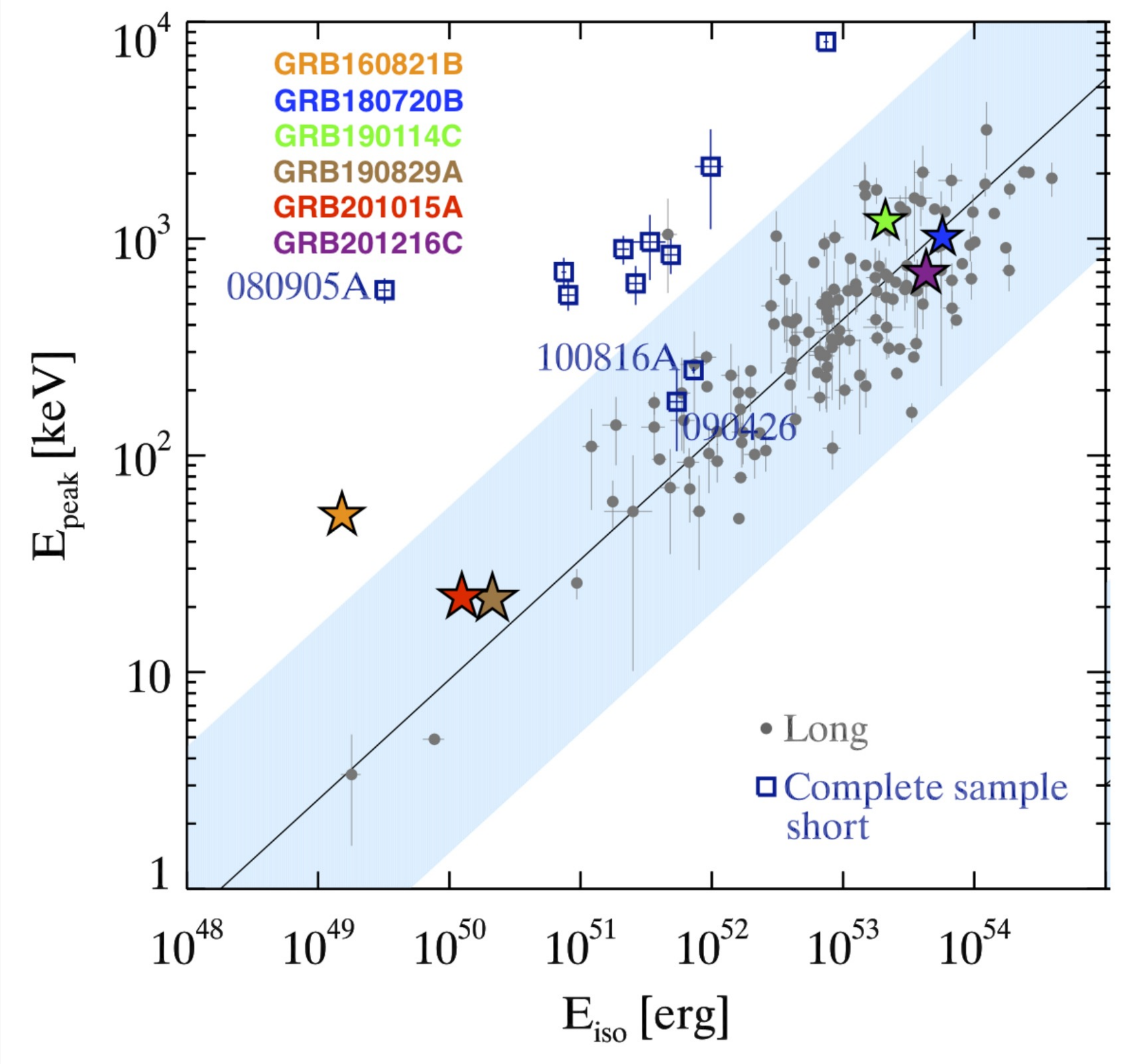
- $L_X \propto E_{\gamma,iso}$
- L_{VHE} ~15-60% L_X



Miceli & Nava, 2022

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
  - $\varepsilon_e \sim 0.1$, $\varepsilon_B \sim 10^{-5}$–$10^{-3}$, $\xi<1$



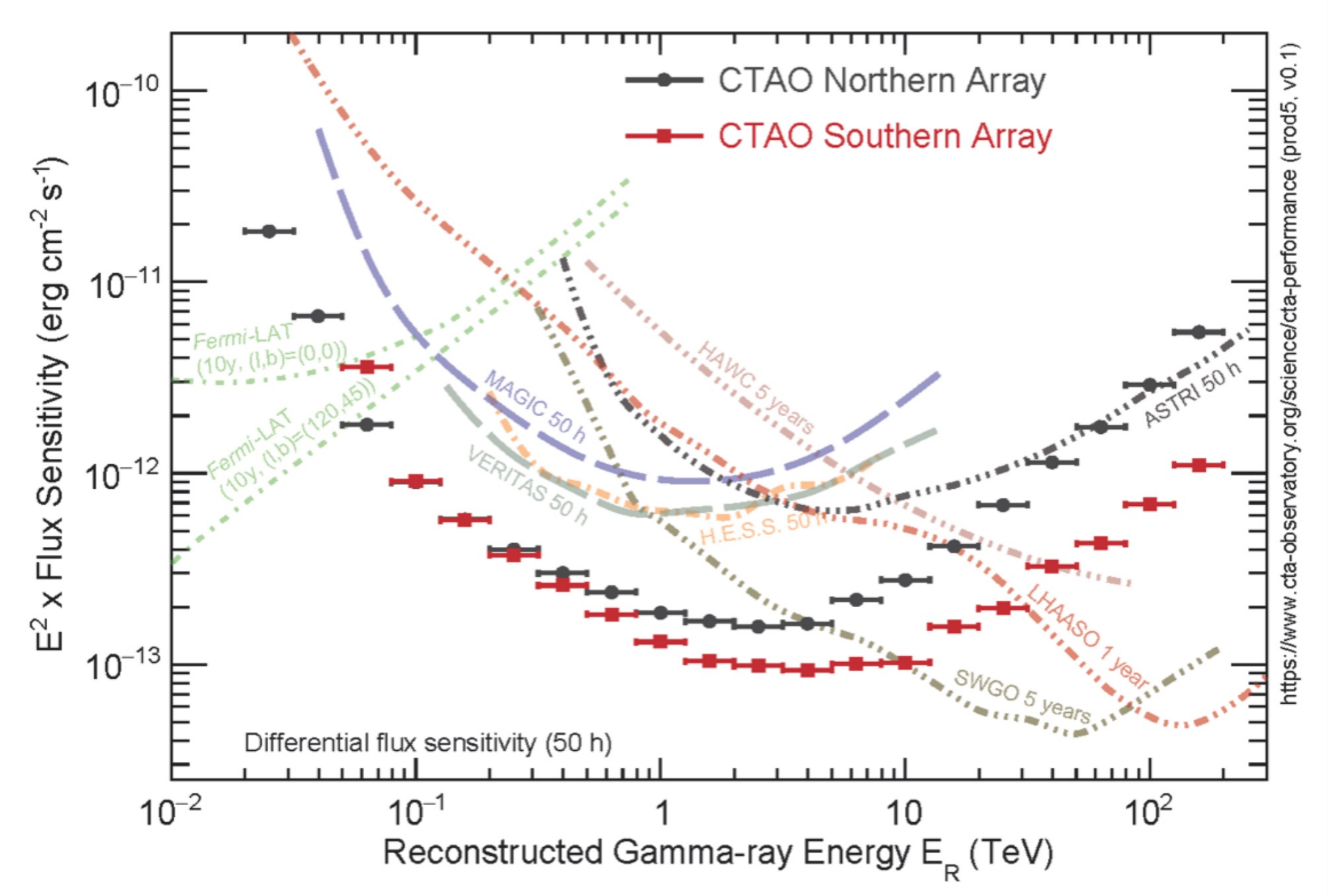
Miceli & Nava, 2022, adapted from D'Avanzo et al. 2014

Future facilities: CTA

CTA upgrades:

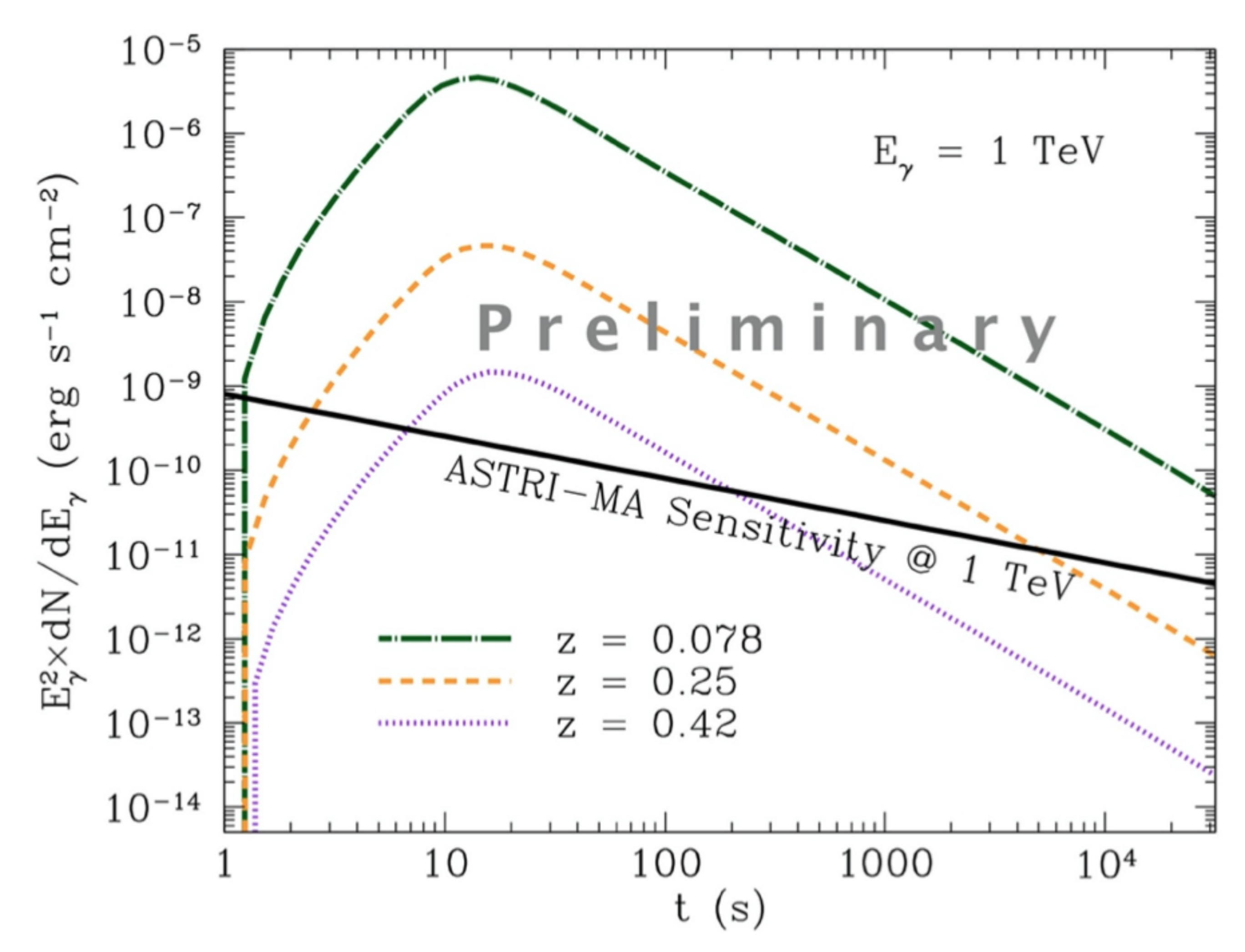
- a lower energy threshold (<30 GeV)
- a larger effective area at multi-GeV energies (~ 10^4 times larger than Fermi-LAT at 30 GeV)
- a rapid slewing capability (180 degrees azimuthal rotation in 20 s).
- a full sky coverage

A few GRBs per year…



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

Future facilities: ASTRI-MA



Stamerra et al.,2021, ICRC

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