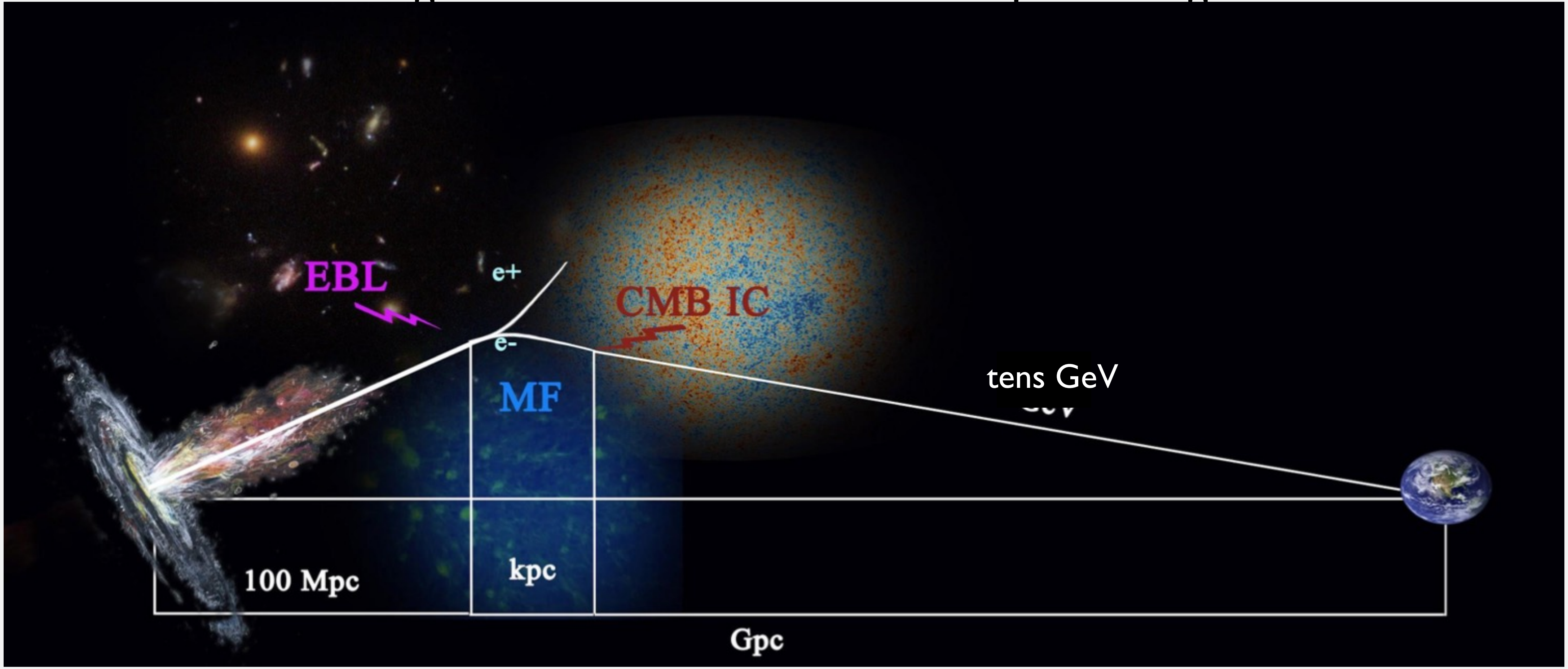
DETECTABILITY OF INTERGALACTIC MAGNETIC FIELD SIGNATURES FROM GAMMA-RAY BURTS WITH IACTs

Davide Miceli, Paolo Da Vela, Elisa Prandini

Cosmic Magnetism in Voids and Filaments, 25/01/2023

Probing Intergalactic Magnetic Field (IGMF) in the GeV range

IGMF can generate an ***extended*** *and* ***time-delayed*** emission at GeV energies due to magnetic field deflection + CMB reprocessing



Adapted from Vachaspati et al. 2020

Imaging Atmospheric Cherenkov Telescopes (IACTs)

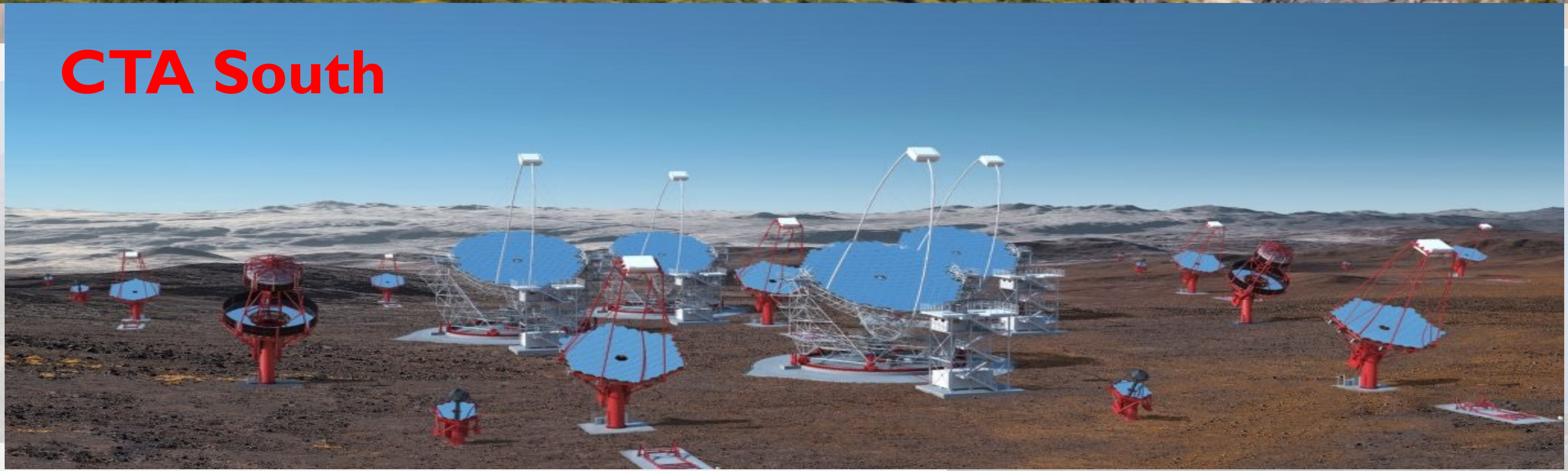
Credit: Robert Wagner/MAGIC Collaboration

Credit: Klepser, DESY, H.E.S.S. collaboration

Credit: VERITAS

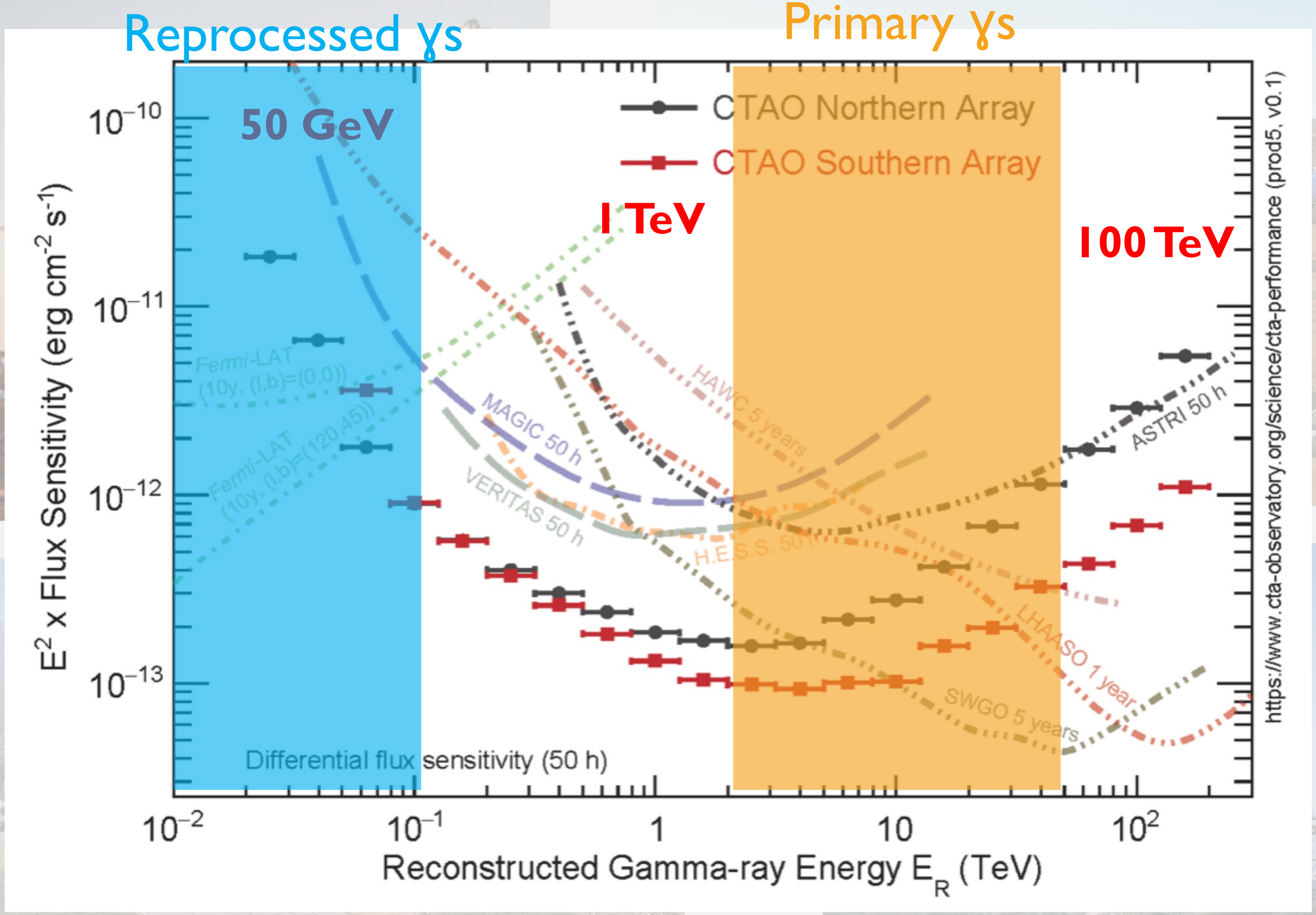
Credit: Tomohiro Inada, CTAO

Imaging Atmospheric Cherenkov Telescopes (IACTs)



Credit: Gabriel Pérez Diaz, IAC / Marc-André Besel, CTAO

Imaging Atmospheric Cherenkov Telescopes (IACTs)



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

IGMF studies

Blazars

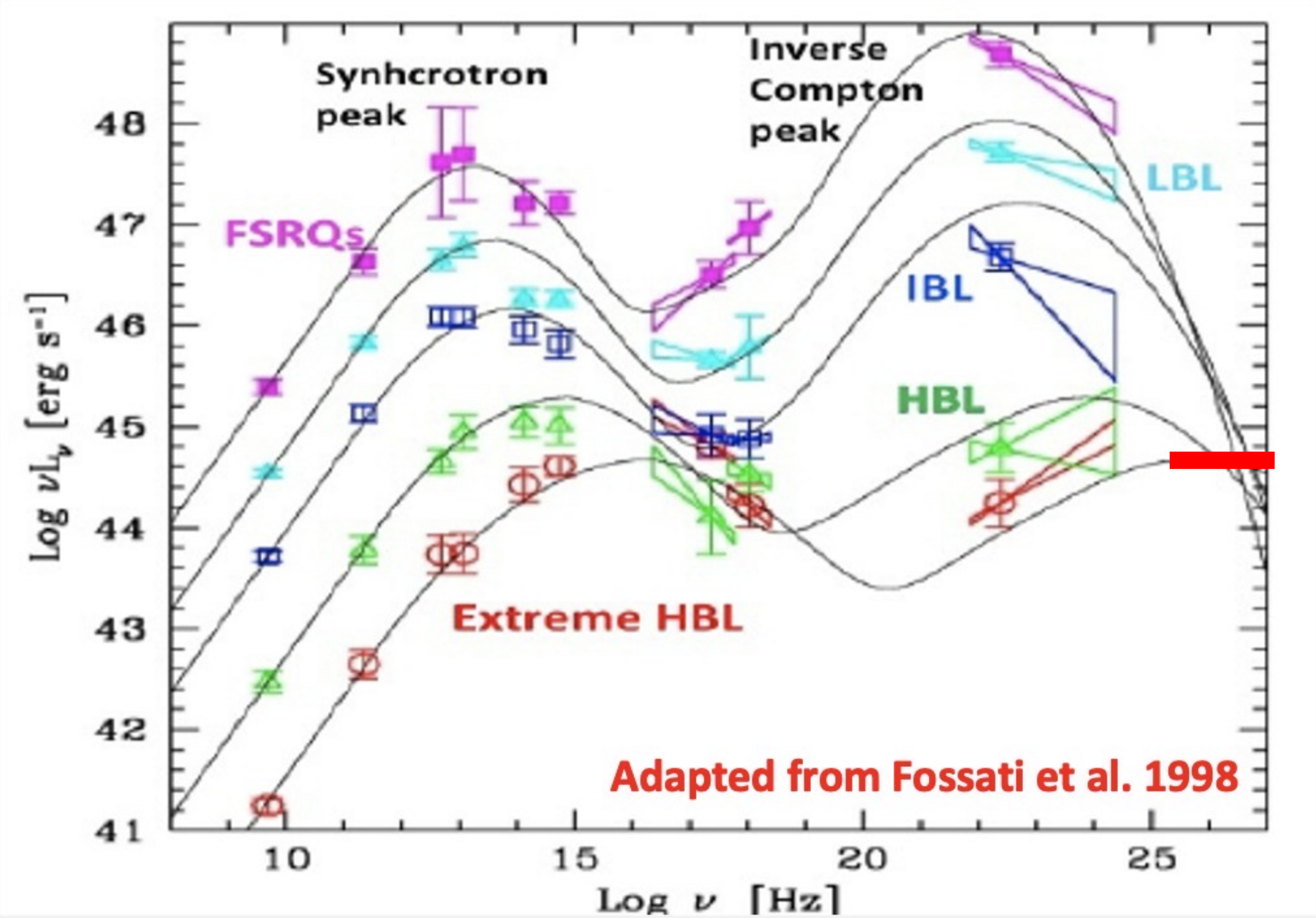
Features:

- Persistent sources of TeV radiation
- Subclass with Hard-TeV spectrum
- Population of ~ 80 sources as TeV

emitters

Drawbacks:

- Source temporal (min-yrs) and spectral variability
- Pollution by primary GeV emission
- Unknown duty cycle



IGMF studies

GRBs

Features:

- Cosmological sources
- Bright transient events (L up to ~ 10^{53} erg s^{-1})

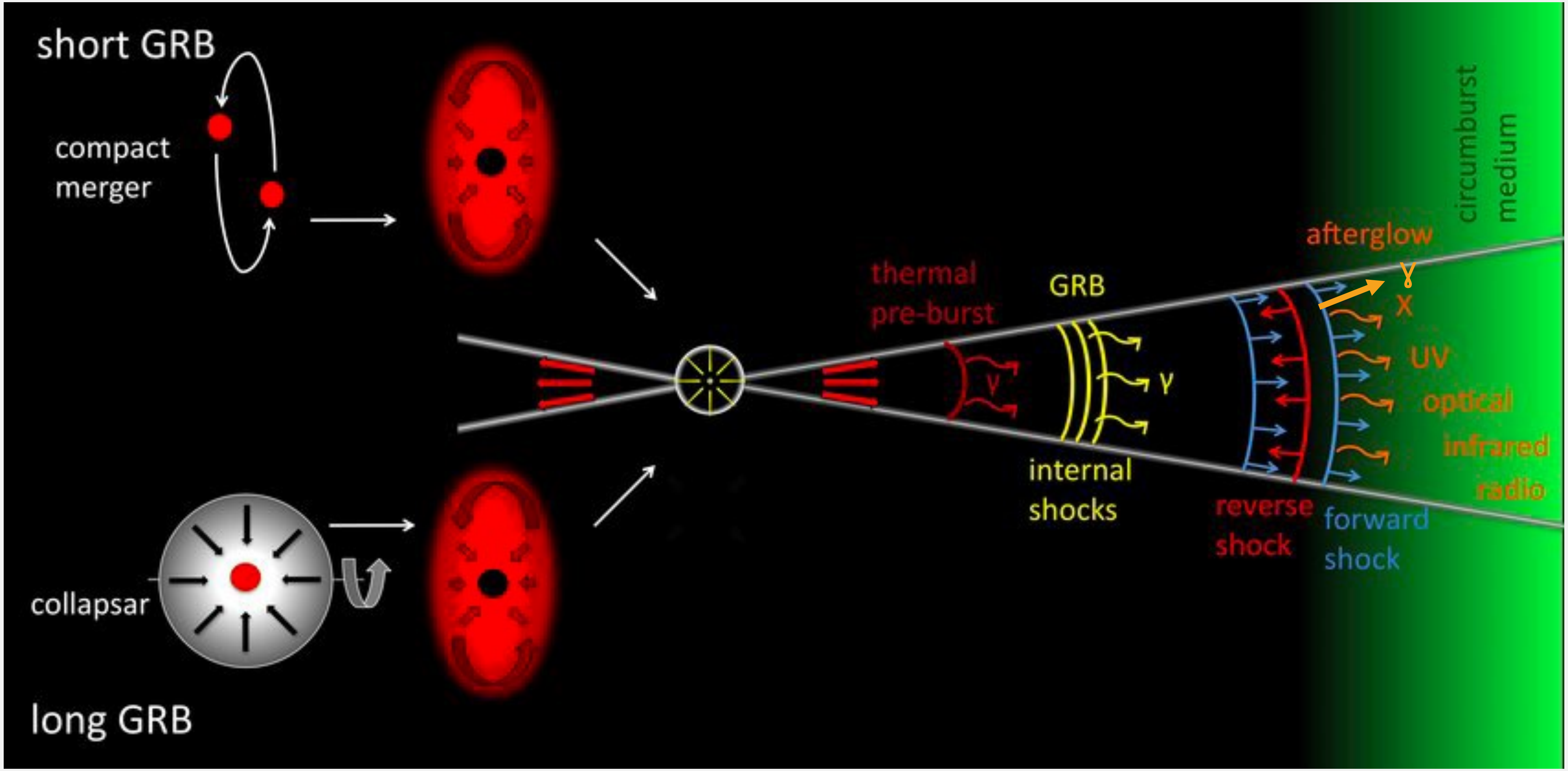
Advantages:

- ~~Pollution by primary GeV emission~~
- ~~Unknown duty cycle~~

Drawbacks:

- Limited number of events (4 events at TeV + 2 hints of TeV emission)
- Source spectrum and spectral variability

Gamma-Ray Bursts (GRBs)



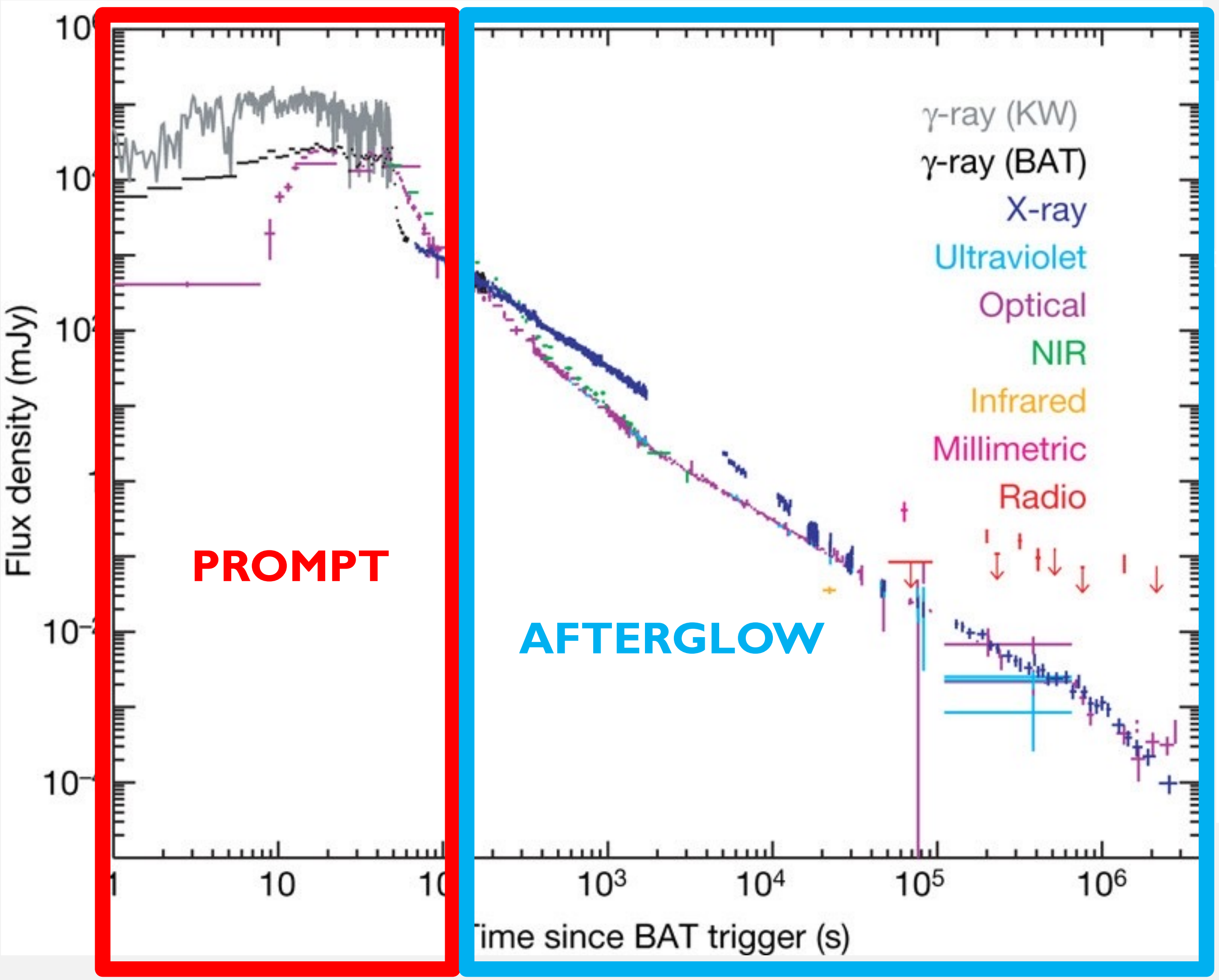
Gamma-Ray Bursts (GRBs)

GRBs at Very High Energy

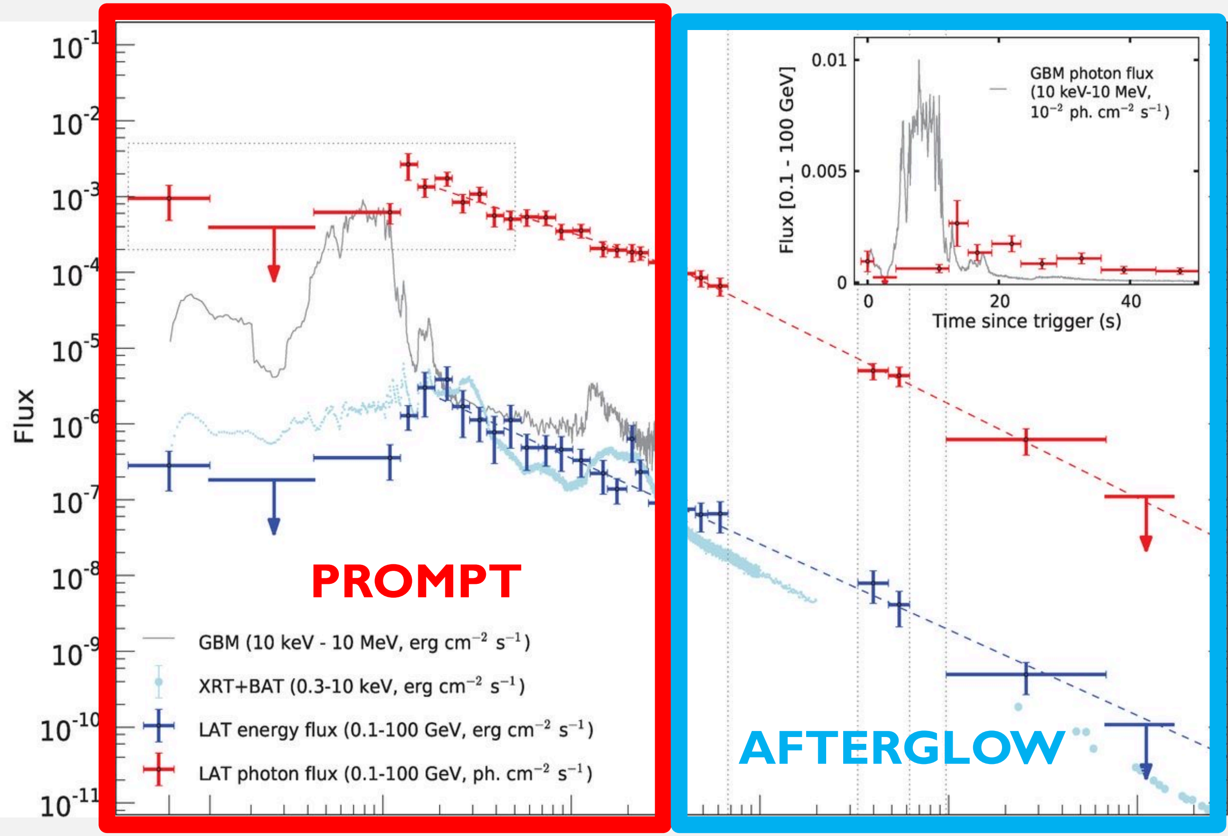
		T_{90} s	$E_{\gamma,iso}$ erg	z	T_{delay} s	E_{range} TeV	IACT (sign.)
Short	160821B	0.48	1.2×10^{49}	0.162	24	0.5-5	MAGIC (3.1σ)
Long	180720B	48.9	6.0×10^{53}	0.654	3.64×10^{4}	0.1-0.44	H.E.S.S. (5.3σ)
Long	190114C	362	2.5×10^{53}	0.424	57	0.3-1	MAGIC ($> 50\sigma$)
Long	190829A	58.2	2.0×10^{50}	0.079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

Miceli & Nava, 2022

Gamma-Ray Bursts (GRBs)



GRB080319B (Racusin et al., 2008)



GRB130427A (Ackermann et al., 2013)

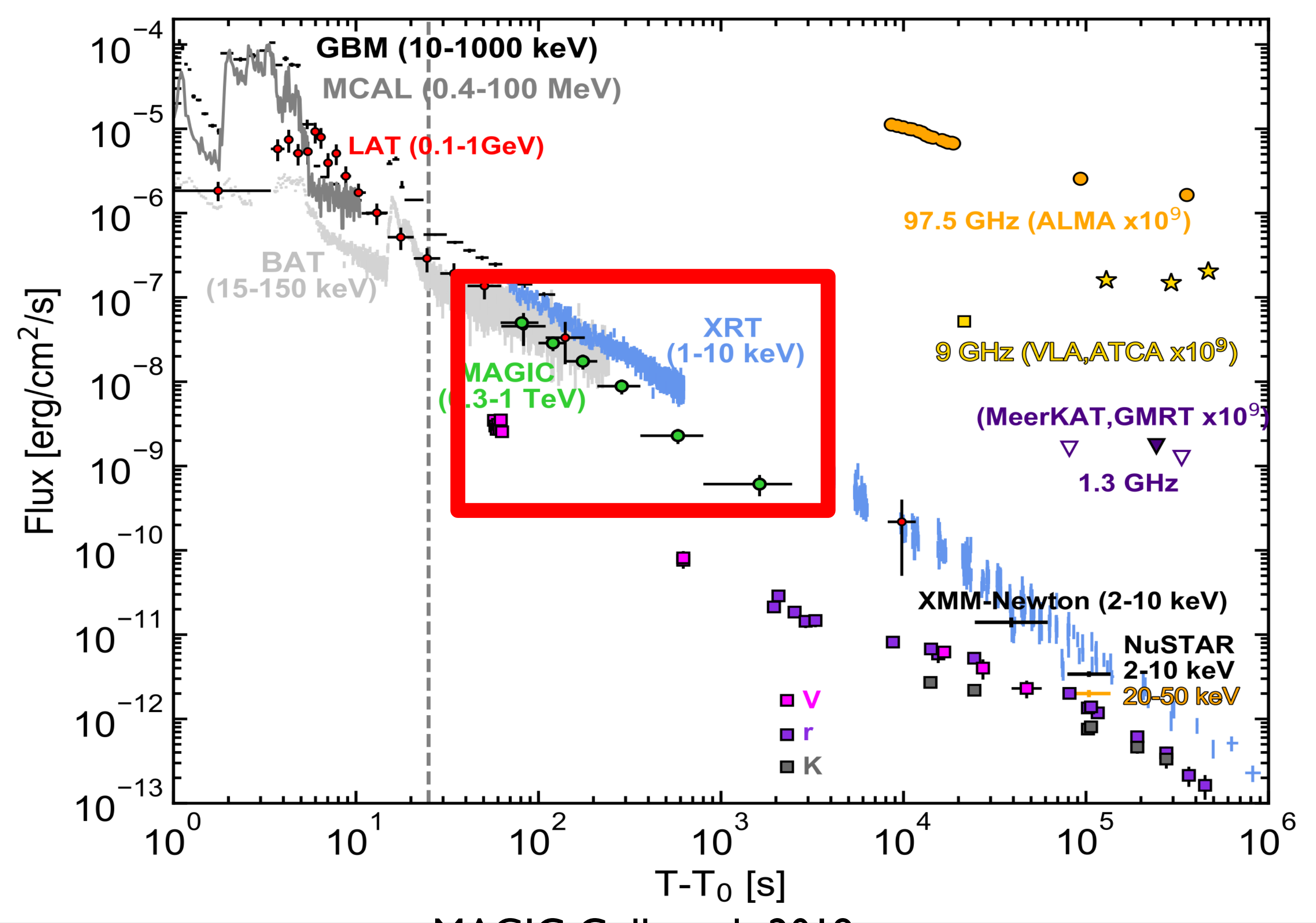
GRB190114C

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

TeV detection info (MAGIC):

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

Multi-wavelength light curve



MAGIC Coll. et al., 2019

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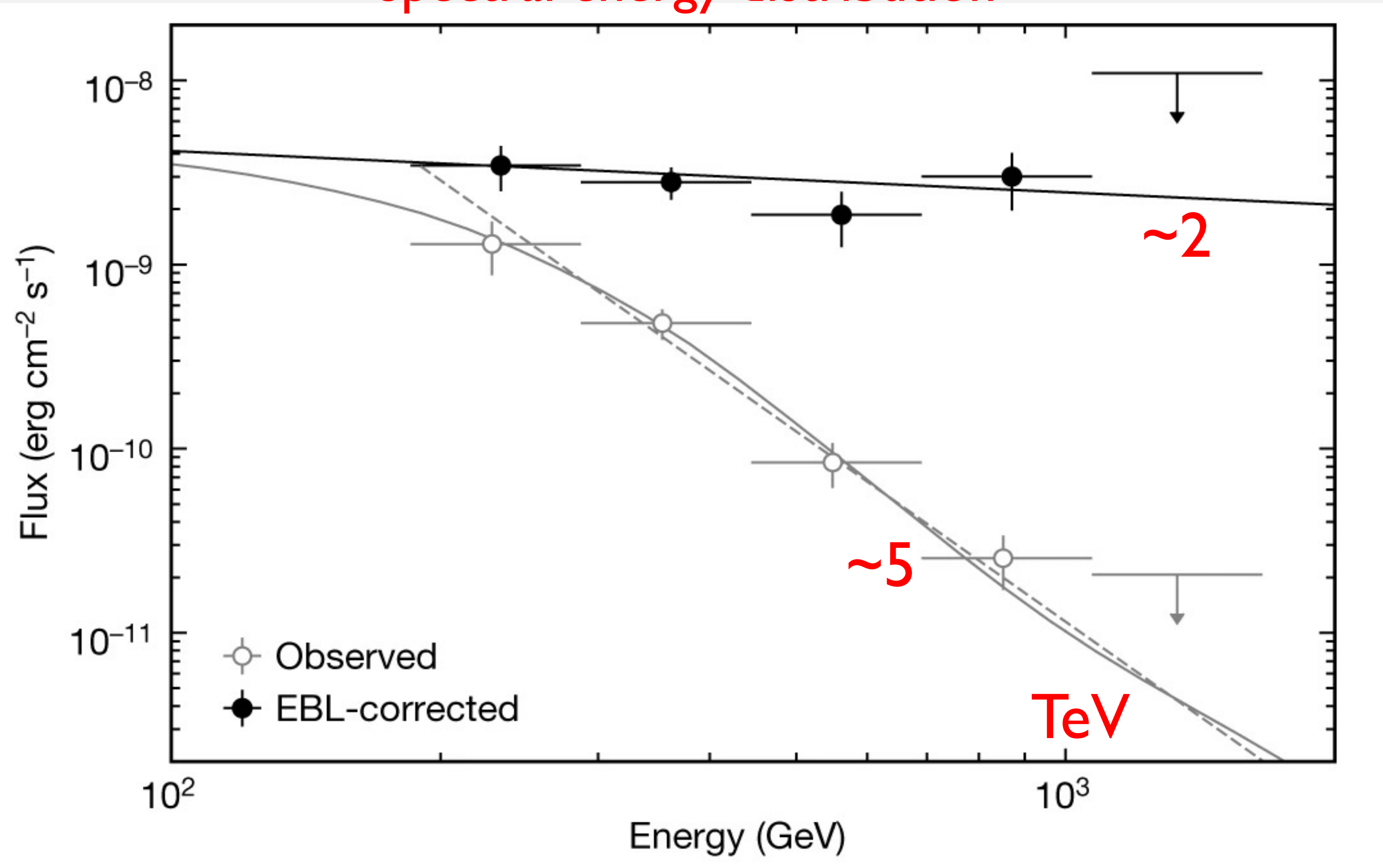
Spectral energy distribution



MAGIC Coll. et al., 2019

GRB190114C: Simulated echo emission

Purpose: calculate the simulated secondary cascade with ***CRPropa***

- Details of CRPropa (Source; Magnetic Field; Observer)
- Assumptions:
    - Starting time for photon cascade counting: 2400 s
    - Source time activity: MAGIC detection interval (40 min)
    - No spectral variability with time (consistent with MAGIC results)
    - Median flux emitted in afterglow phase

GRB190114C: Simulated echo emission

Estimate the median flux emitted in the afterglow phase in TeV range

- Afterglow starting phase → ~ 6 s (Ravasio et al. 2019)

MAGIC LC fit in [0.3 – 1] TeV from 68 s up to 2400 s

↓

Flux extrapolated from 6 s up to 2400 s

GRB190114C: Simulated echo emission

Estimate the median flux emitted in the afterglow phase in TeV range

Assumed photon (EBL-deabsorbed) spectrum in [0.2 - 10] TeV:

- Power-law spectrum

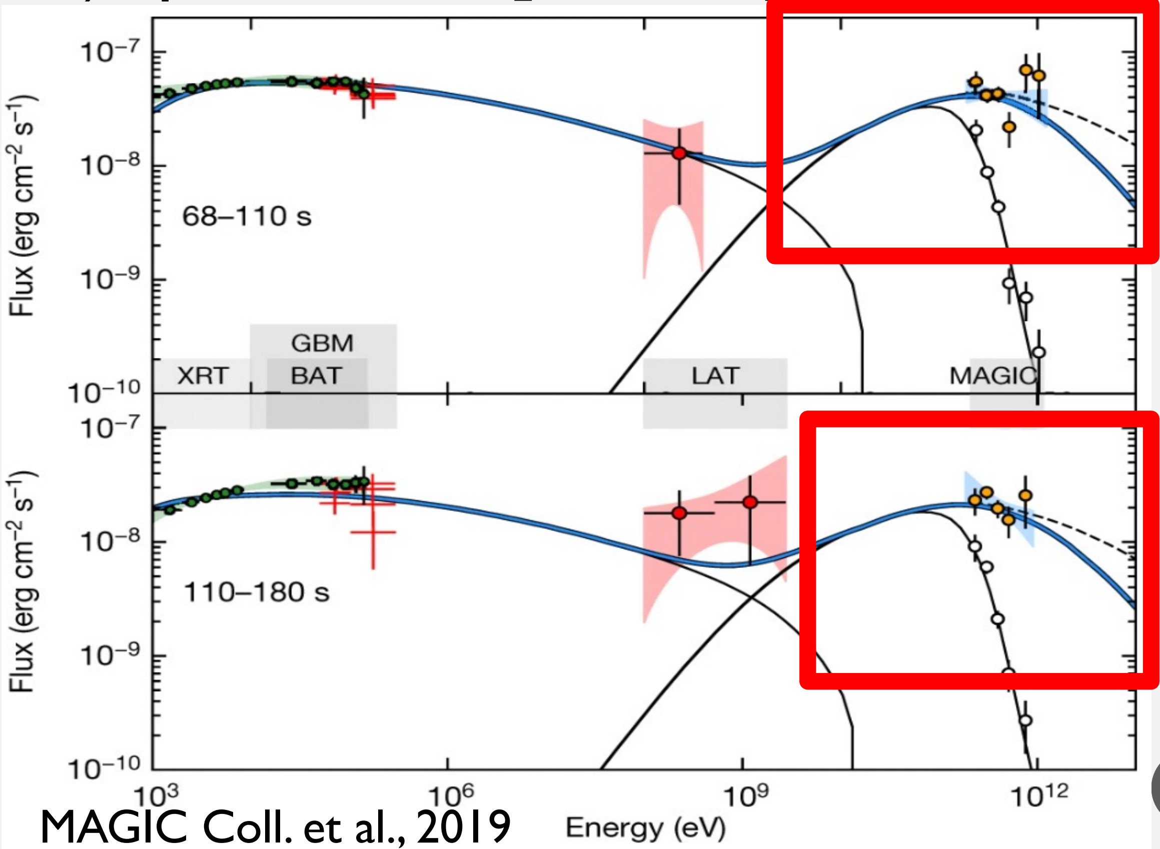
↓

too optimistic assumption

- Log-parabola spectrum

↓

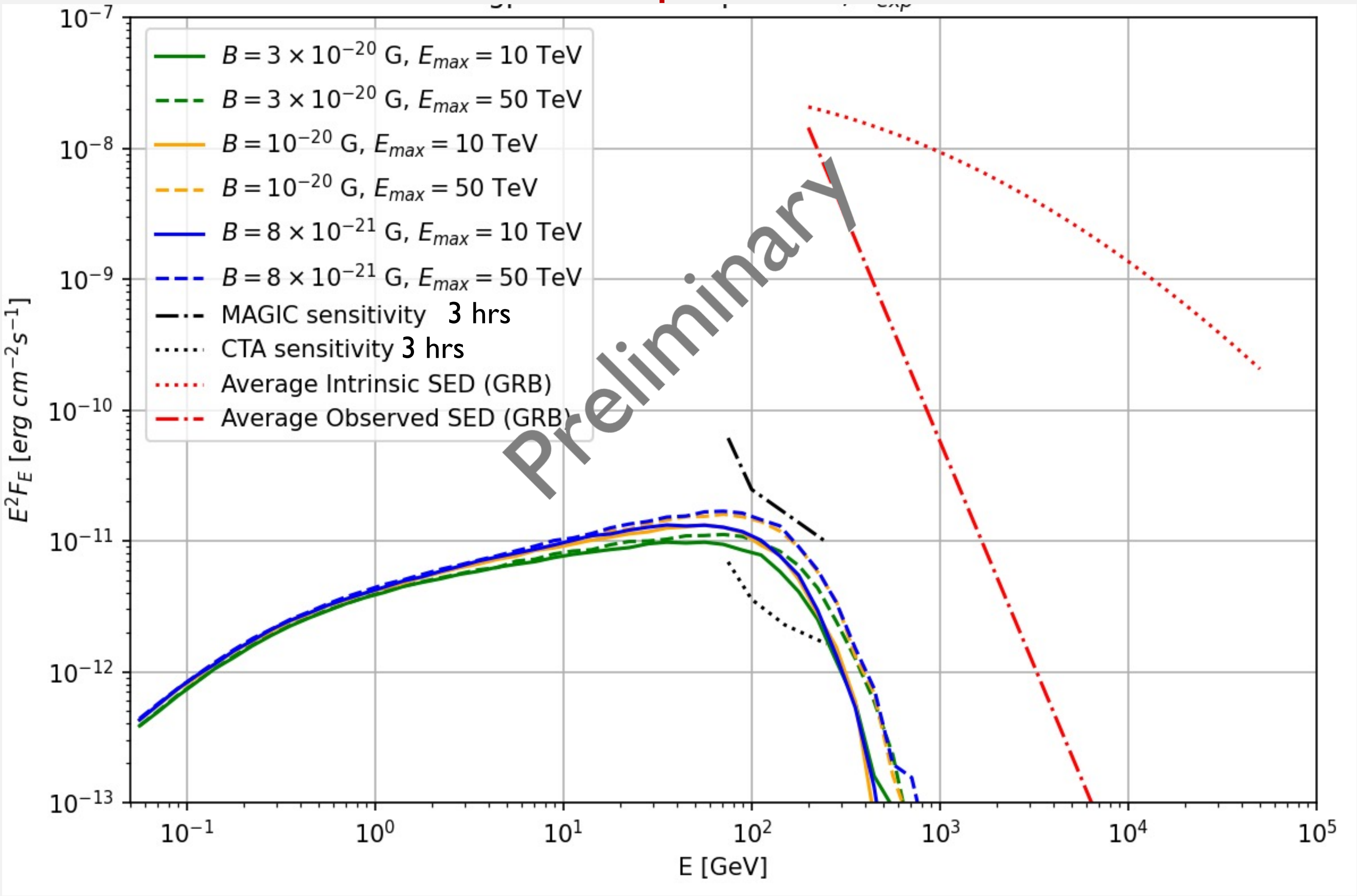
consistent with data modeling and theoretical expectations



MAGIC Coll. et al., 2019

GRB190114C (z = 0.42)

Comparison with MAGIC and CTA sensitivities

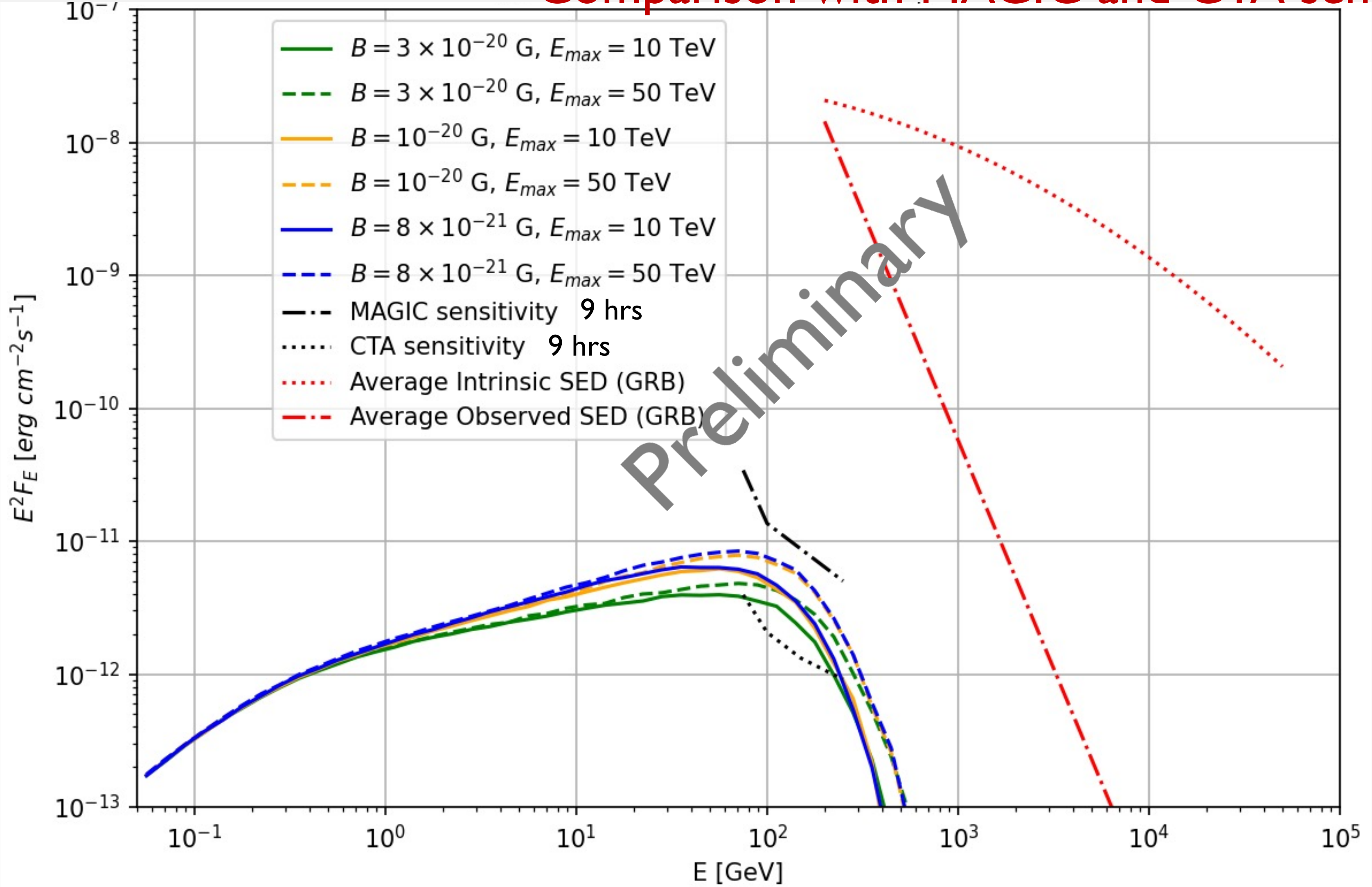


Spectral energy distribution

- Primary GRB emission
- Secondary emission
- Observational time: **3 hours** starting from 2400 s after trigger burst
- MAGIC and CTA sensitivity for transients from Fioretti et al, 2019

GRB190114C (z = 0.42)

Comparison with MAGIC and CTA sensitivities

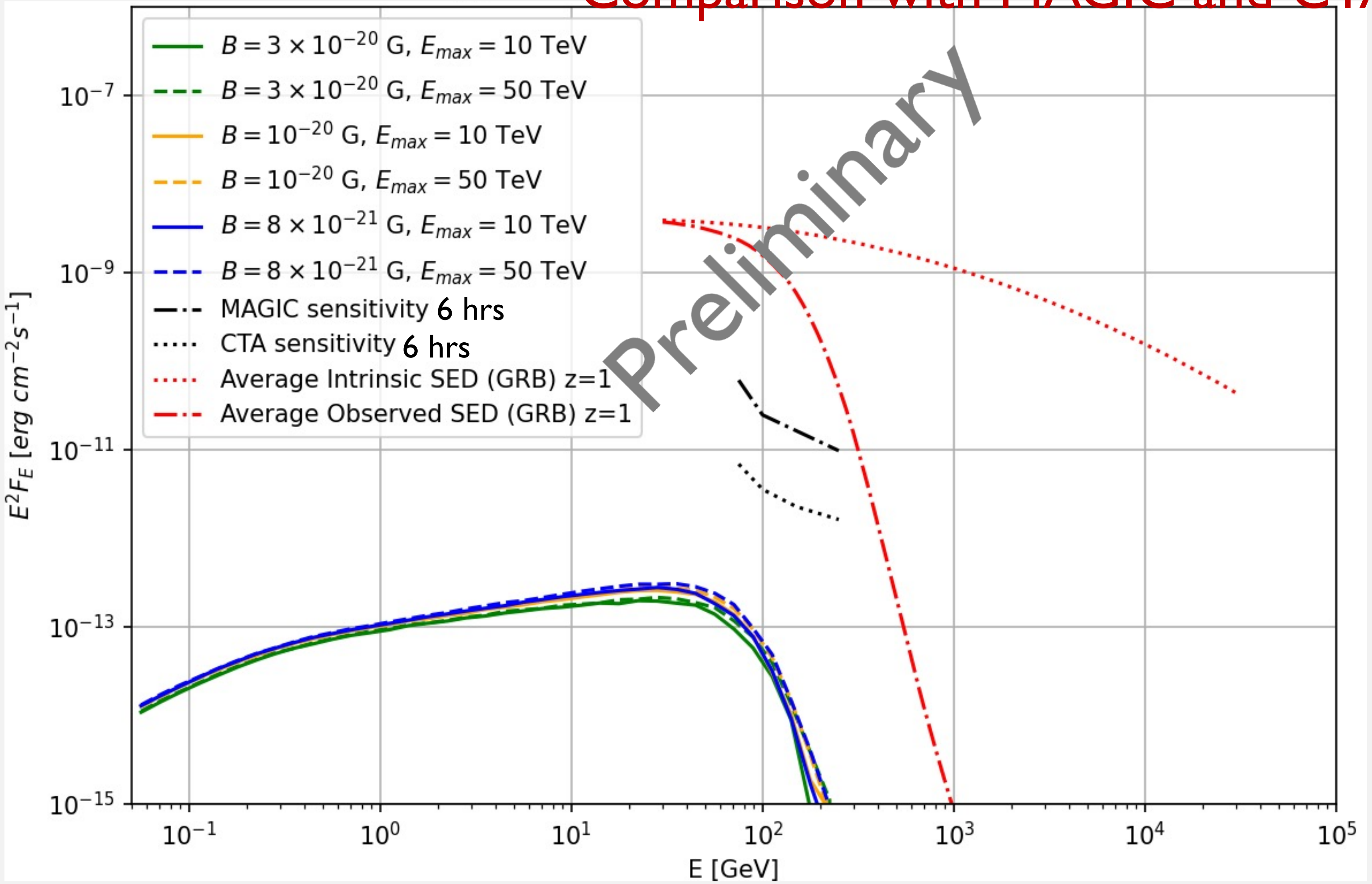


Spectral energy distribution

- Primary GRB emission
- Secondary emission
- Observational time: **9 hours** starting from 2400 s after trigger burst
- MAGIC and CTA sensitivity for transients from Fioretti et al, 2019

GRB190114C-like with higher redhshift **(z = 1.0)**

Comparison with MAGIC and CTA sensitivities

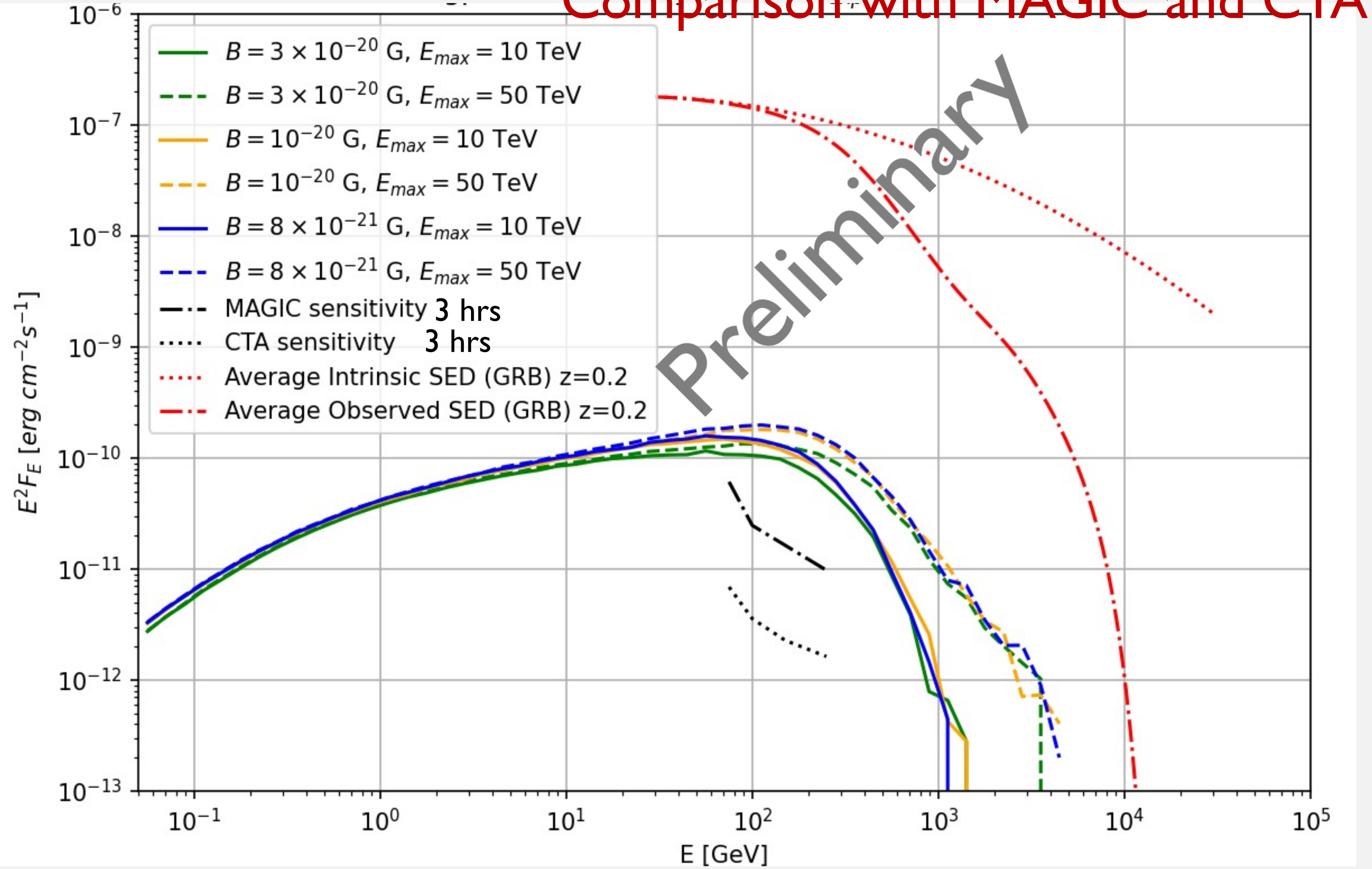


Spectral energy distribution

- Primary GRB emission
- Secondary emission
- Observational time: **6 hours** starting from 2400 s after trigger burst
- MAGIC and CTA sensitivity for transients from Fioretti et al, 2019

GRB190114C-like with lower redhshift **(z = 0.2)**

Comparison with MAGIC and CTA sensitivities



Spectral energy distribution

- Primary GRB emission
- Secondary emission
- Observational time: **3 hours** starting from 2400 s after trigger burst
- MAGIC and CTA sensitivity for transients from Fioretti et al, 2019

GRB221009A (z = 0.151)

```
TITLE:   GCN CIRCULAR
NUMBER:
SUBJECT: LHAASO observed GRB 221009A with more than 5000 VHE photons up to around 18 TeV
DATE:
FROM:    Judith Racusin at GSFC  &lt;judith.racusin@nasa.gov&gt;

Yong Huang, Shicong Hu, Songzhan Chen,  Min Zha, Cheng Liu, Zhiguo Y
Zhen Cao report on behalf of the LHAASO experiment

We report the observation of GRB 221009A, which was detected by Swif
et al. GCN #32635), Fermi-GBM (Veres et al. GCN #32636, Lesage et al
Fermi-LAT (Bissaldi et al. GCN #32637), IPN (Svinkin et al. GCN #326

GRB 221009A is detected by LHAASO-WCDA at energy above 500 GeV, cent
RA = 288.3, Dec = 19.7 within 2000 seconds after T0, with the signif
100 s.d., and is observed as well by LHAASO-KM2A with the significan
where the energy of the highest photon reaches 18 TeV.

This represents the first detection of photons above 10 TeV from GRB

The LHAASO is a multi-purpose experiment for gamma-ray astronomy (in
band between 10^11 and 10^15 eV) and cosmic ray measurements.
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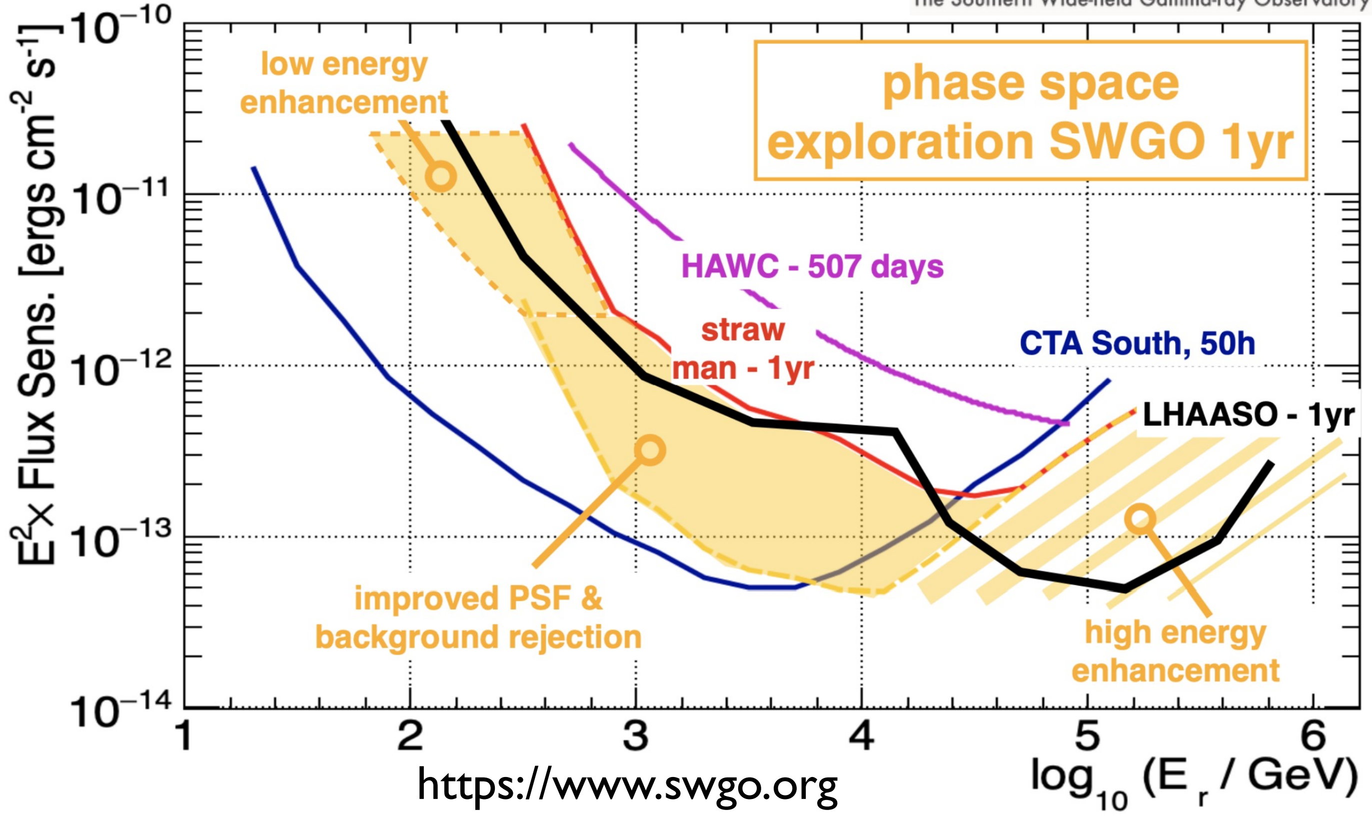
The Southern Wide-field Gamma-ray Observatory



Current and future Extended Air Shower (EAS) can provide useful results

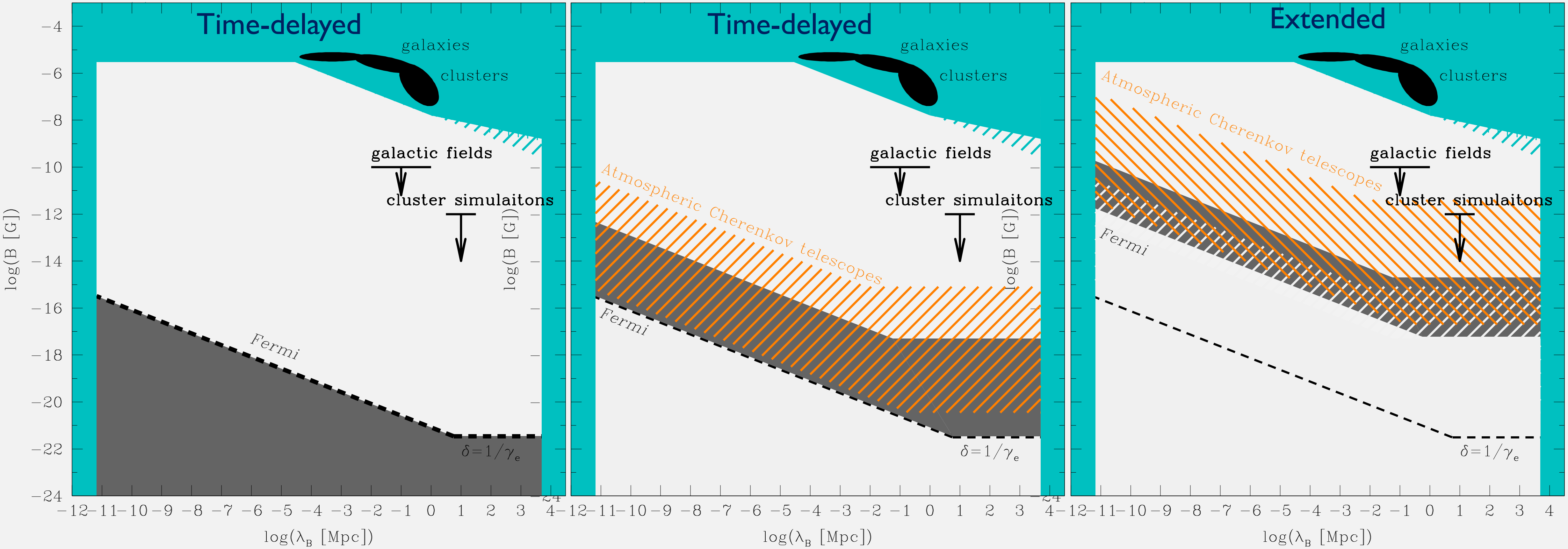
Conclusions

- Gamma-Ray Bursts are promising sources for IGMF studies
- Current IACTs can probe the ”weakest” IGMFs **extending observational time** (3-6-9 h) in follow-up nearby and bright GRBs
- Impact of intrinsic source features is greater than secondary reprocessing due to distance
- Future facilities (CTA, SWGO) will play a key role (IGMF studies from GRBs as a key project)

BACKUP SLIDES

Probing IGMF in the GeV range

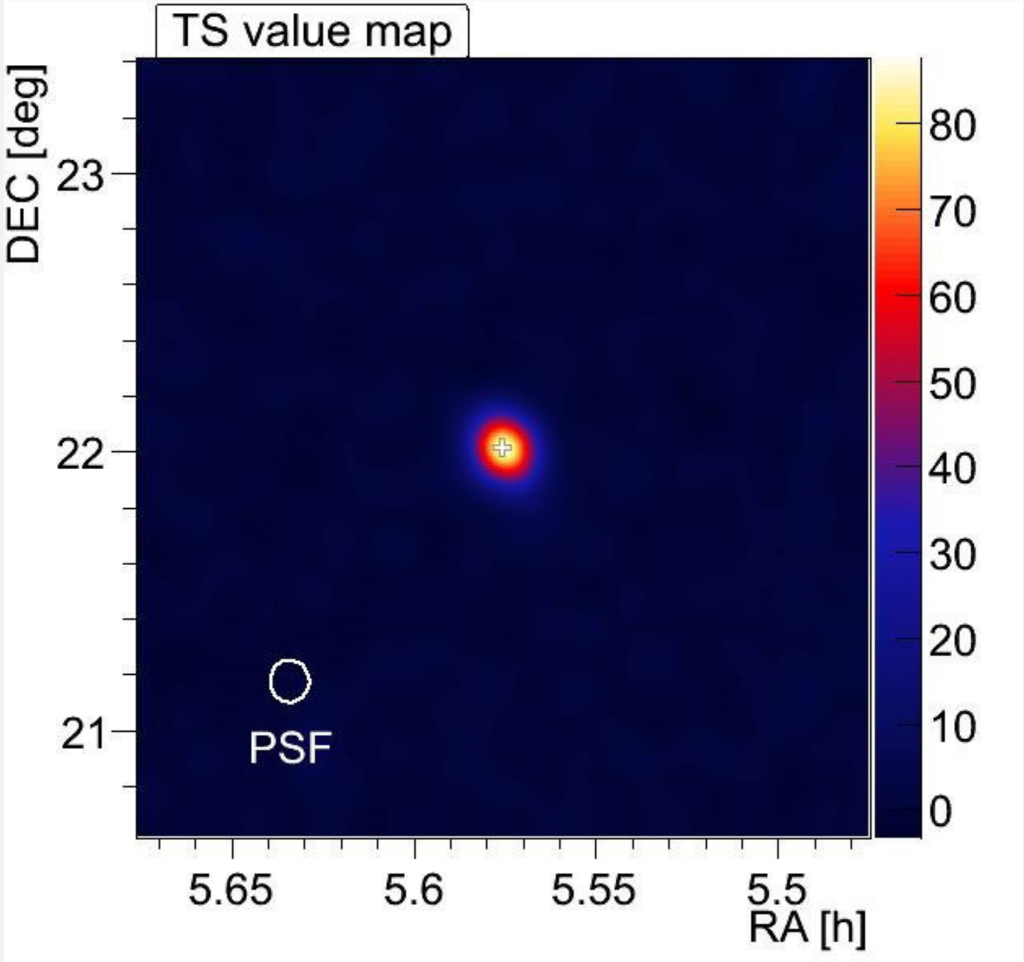
IGMF can generate an ***extended*** *and* ***time-delayed*** emission at GeV energies due to magnetic field deflection + CMB reprocessing



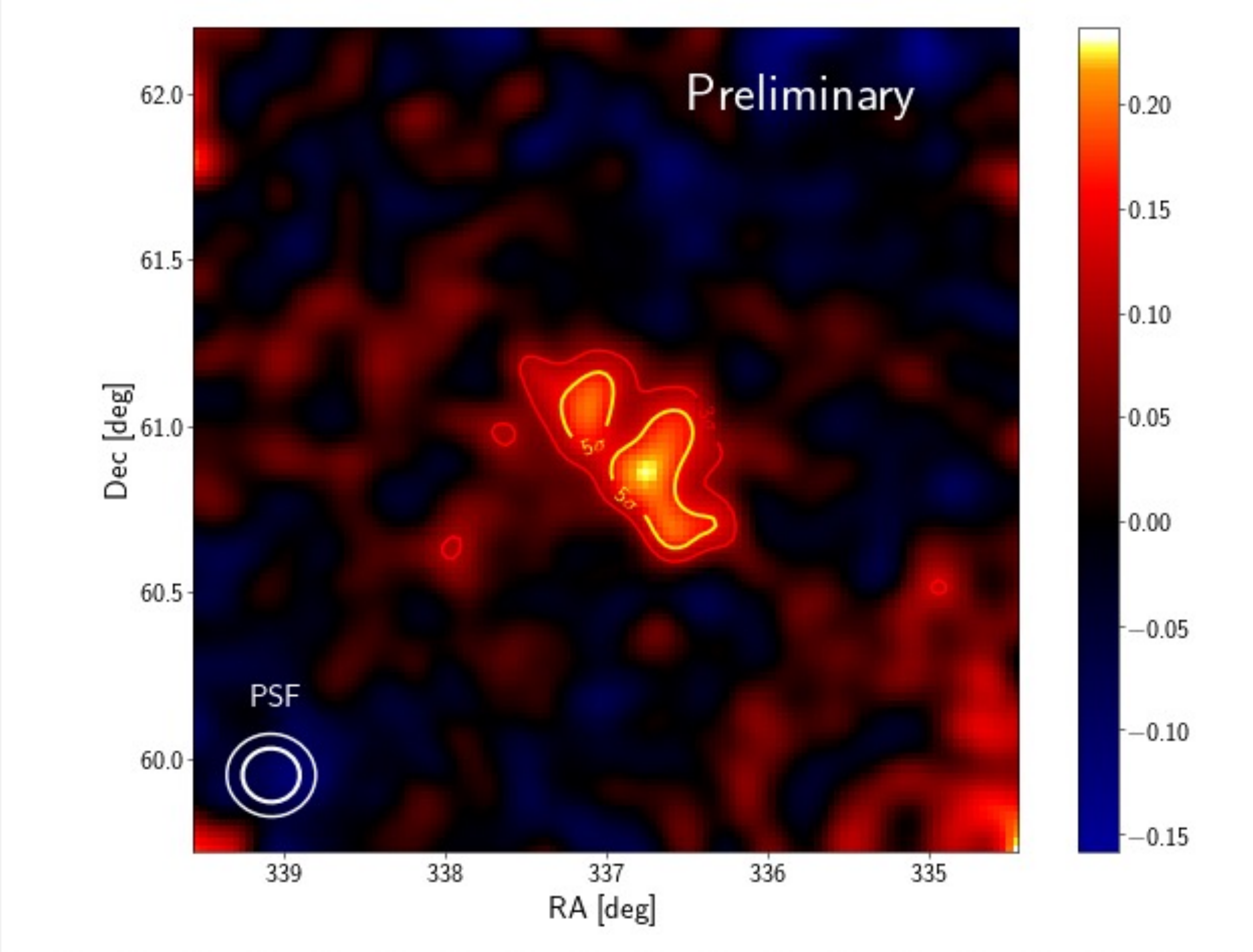
Neronov et al, 2009

IGMF: Extended emission

Point-like source

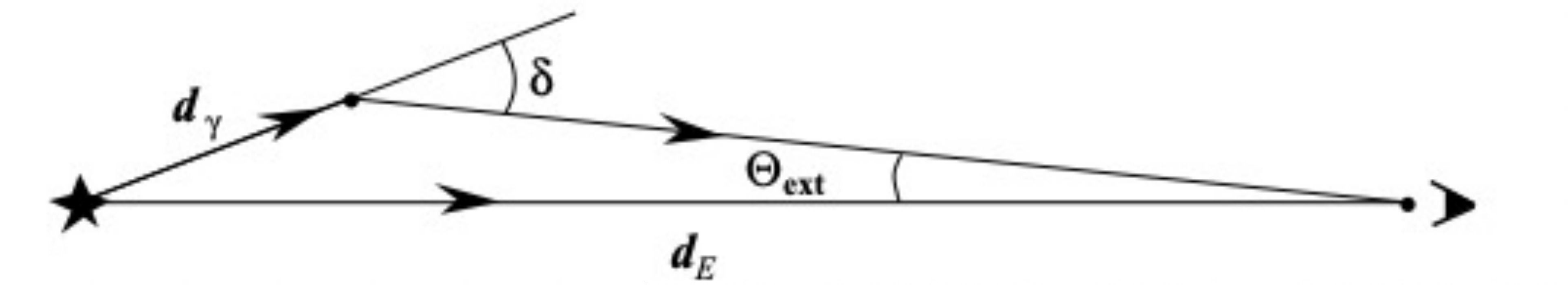


Extended source



IGMF: Extended emission

Deflection angle (δ) and angular extention (θ_{ext}) are sensitive to magnetic field B, energy of reprocessed photons (E_γ) and source distance (z)

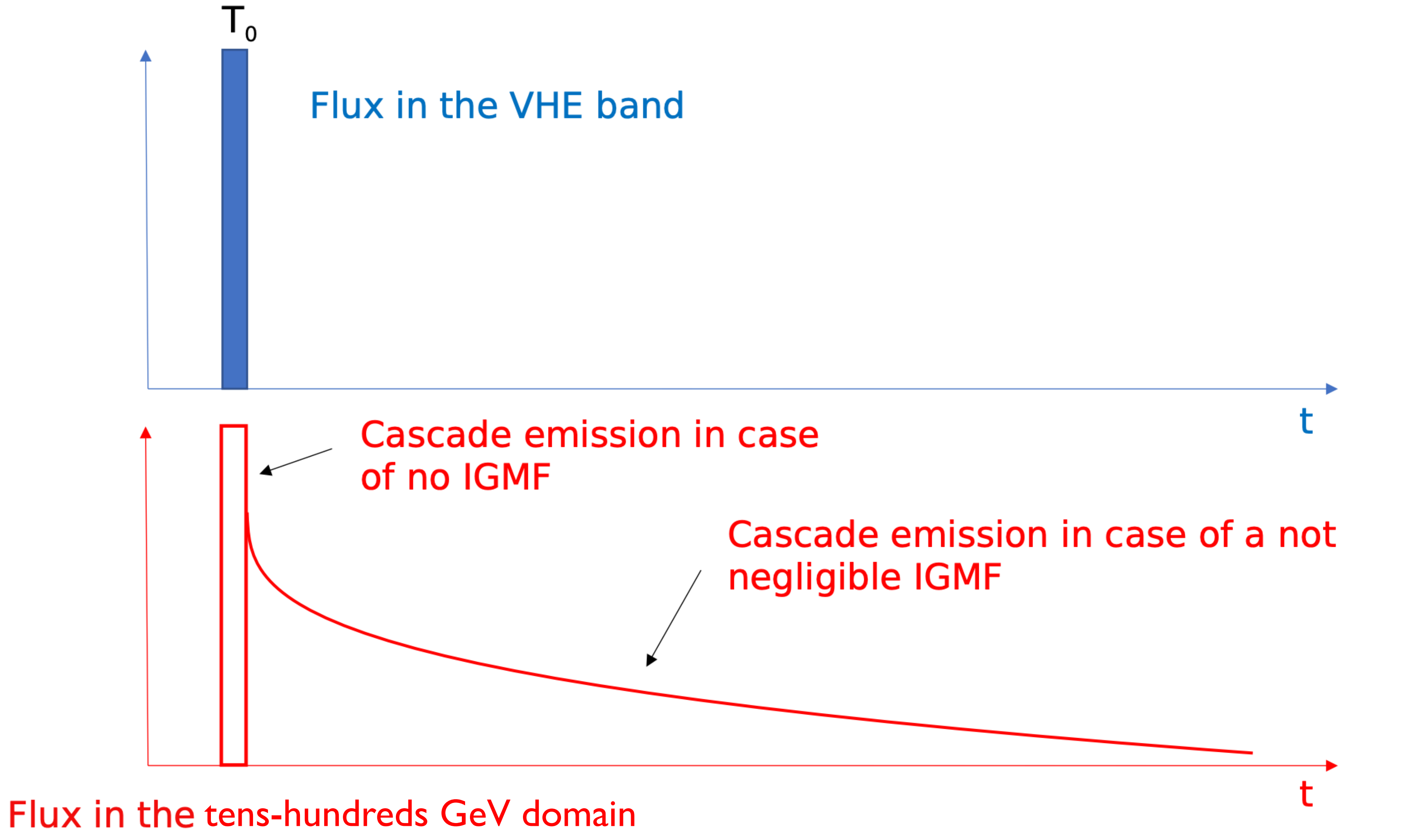


$$\delta = \frac{D_e}{R_L} \simeq 3\times10^{-6}(1+z_{\gamma\gamma})^{-4}\left[\frac{B'}{10^{-18}\ \mathrm{G}}\right]\left[\frac{E'_e}{10\ \mathrm{TeV}}\right]^{-2}$$
$$\simeq 3\times10^{-6}(1+z_{\gamma\gamma})^{-2}\left[\frac{B_0}{10^{-18}\ \mathrm{G}}\right]\left[\frac{E'_e}{10\ \mathrm{TeV}}\right]^{-2} \quad (30)$$

$$\Theta_{ext} \simeq \begin{cases} 0.5^\circ(1+z)^{-2}\left[\frac{\tau_\theta}{10}\right]^{-1} \left[\frac{E_\gamma}{0.1\ \mathrm{TeV}}\right]^{-1}\left[\frac{B_0}{10^{-14}\ \mathrm{G}}\right], & \lambda'_B \gg D_e \\ 0.07^\circ(1+z)^{-1/2}\left[\frac{\tau_\theta}{10}\right]^{-1} \left[\frac{E_\gamma}{0.1\ \mathrm{TeV}}\right]^{-3/4}\left[\frac{B_0}{10^{-14}\ \mathrm{G}}\right]\left[\frac{\lambda_{B0}}{1\ \mathrm{kpc}}\right]^{1/2}, & \lambda'_B \ll D_e \end{cases}$$

Neronov et al, 2009

IGMF: Time-delayed emission



From Da Vela's talk at TeVPA 2022

$$F_{delay} \sim F_0 \frac{T}{T_{delay} + T}$$

$$T_{delay} \propto B^2 E_\gamma^{-5/2}$$

Interesting for **AGN flares** or **transient** sources