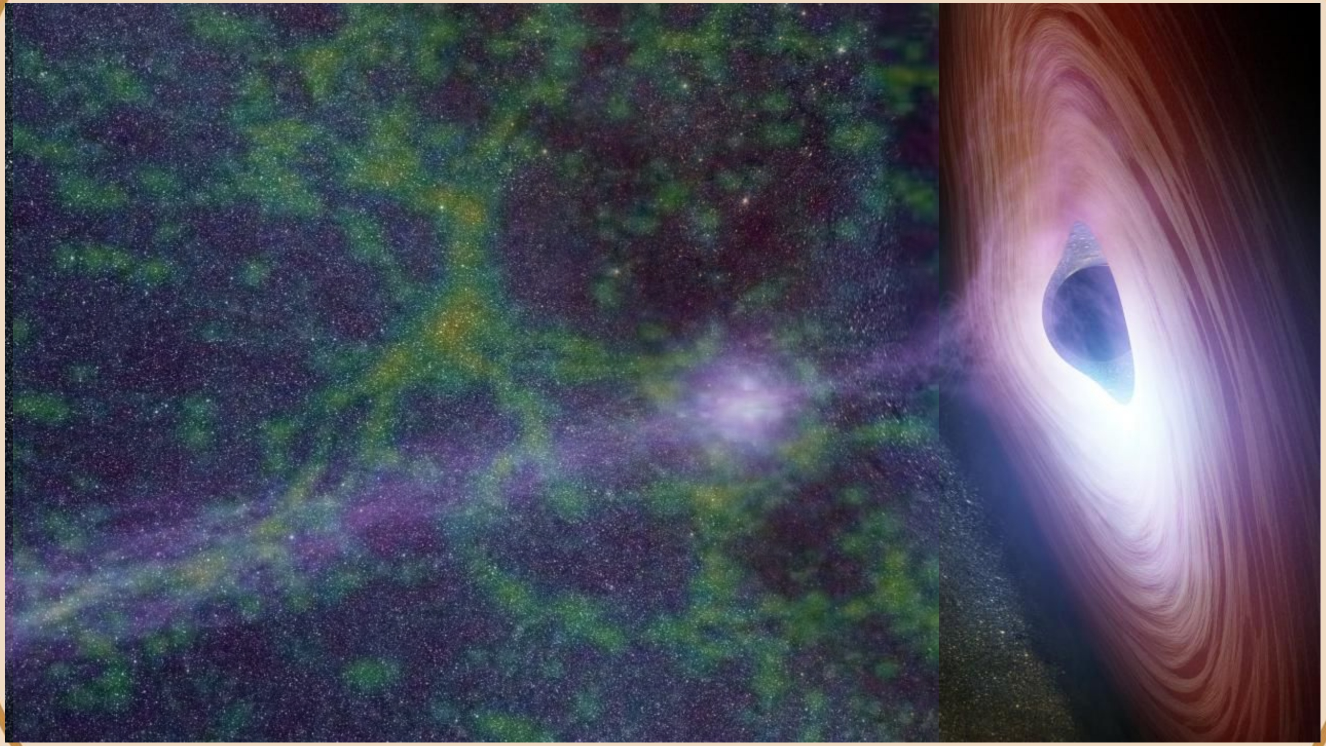
Finanziato dall'Unione europea
NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

INAF
ISTITUTO NAZIONALE DI ASTROFISICA

Prospects for detection of pair-echo emission from TeV gamma-ray bursts



Paolo Da Vela, Davide Miceli, Lara Nava, Giancarlo Ghirlanda, Elisa Prandini

Milano, 2-6 September, 2024

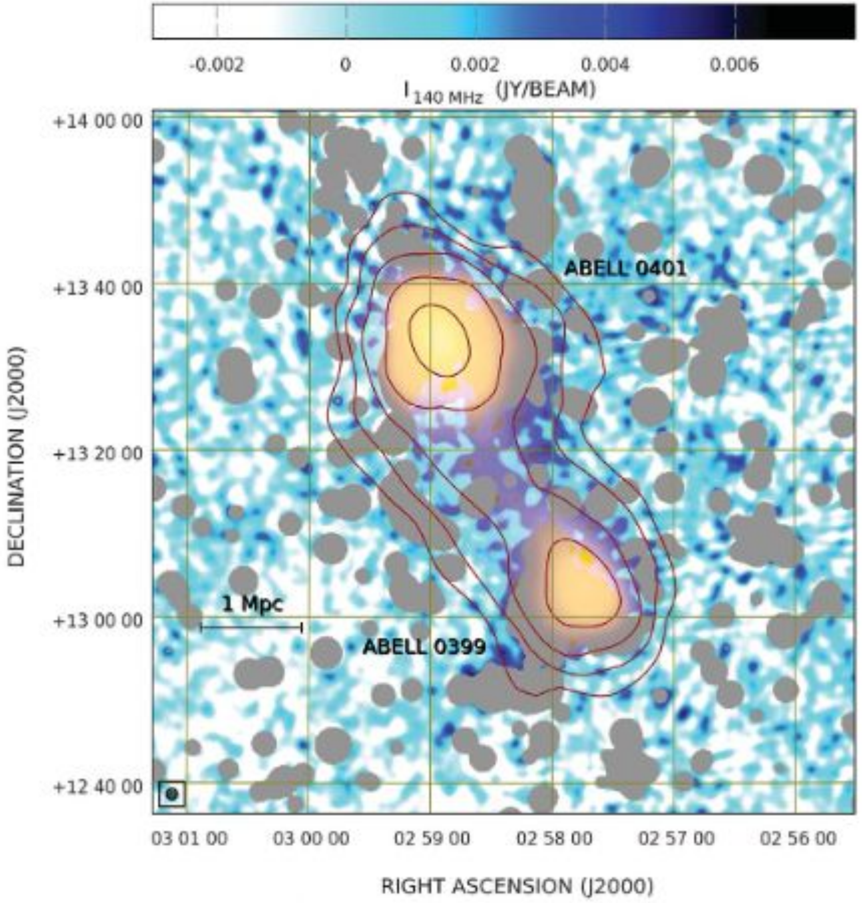
Magnetic Fields in galaxies

Borlaff et al. 2021

B < 1 μG

B ≈15 μG

Most of the models that explain these magnetic fields assume a pre-existing magnetic field



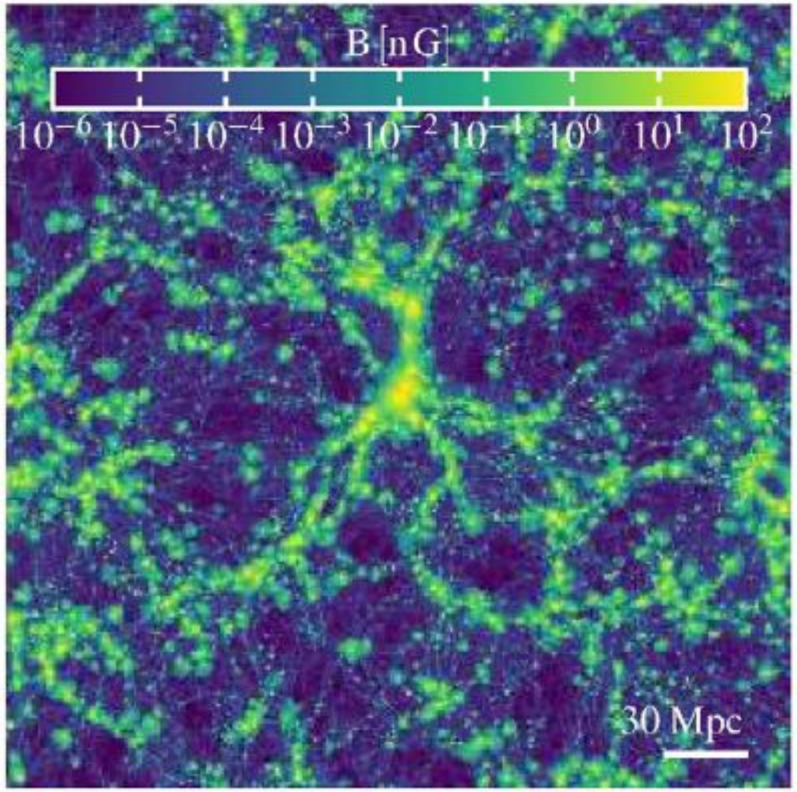
Govoni et al. 2019

On the nature of the seed fields

- The nature of the seed fields is largely unknown. Two main hypothesis exist:

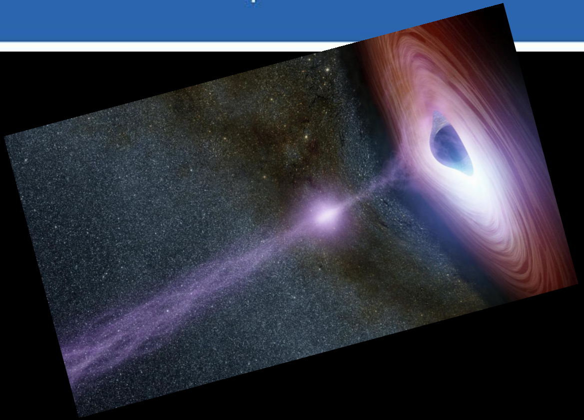
  - the cosmological scenario
  - the astrophysical scenario

- Observationally we need measurement of magnetic fields in the intergalactic medium



Marinacci et al. 2019

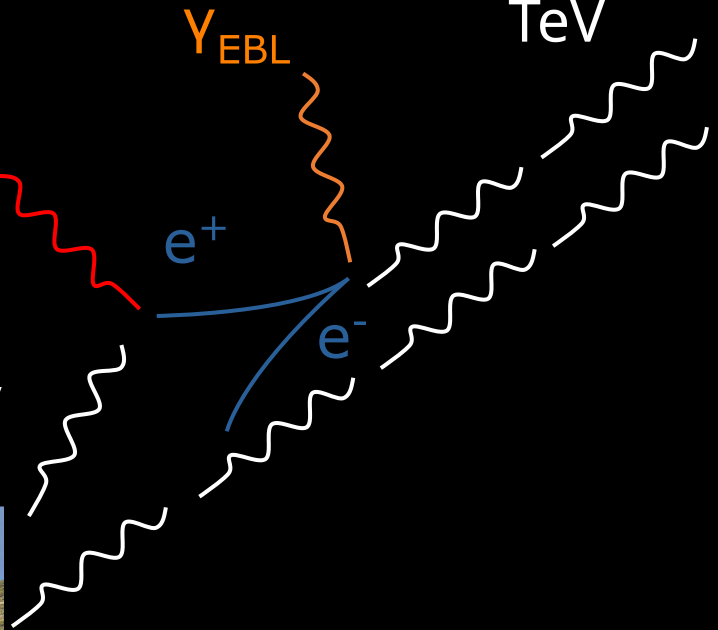
Physical process



Excess at lower energies

$$E \simeq 70 \left[\frac{E_0}{10\,TeV}\right]^2 \quad GeV$$

Neronov et al. 2009



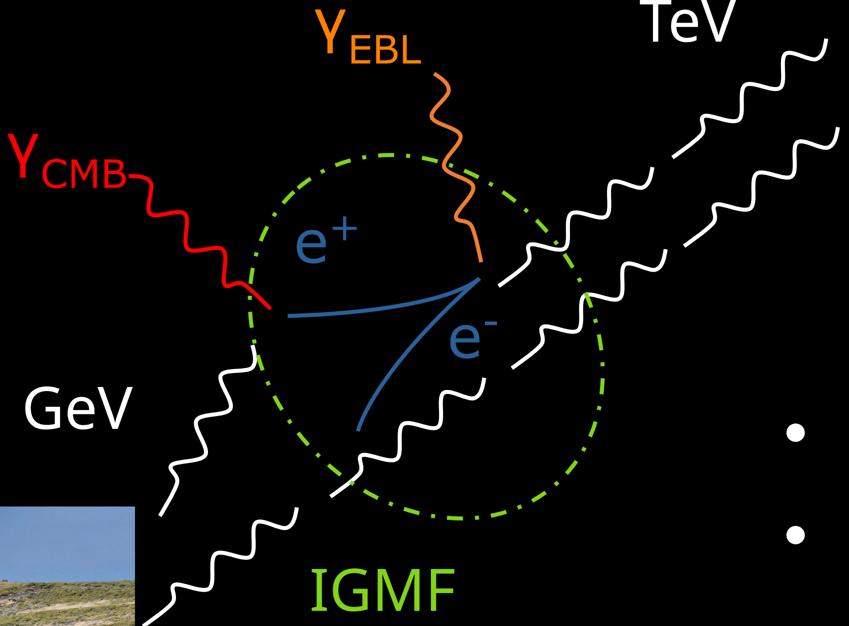
Physical process

Excess at lower energies

$$E \simeq 70 \left[\frac{E_0}{10\,TeV}\right]^2 \quad GeV$$

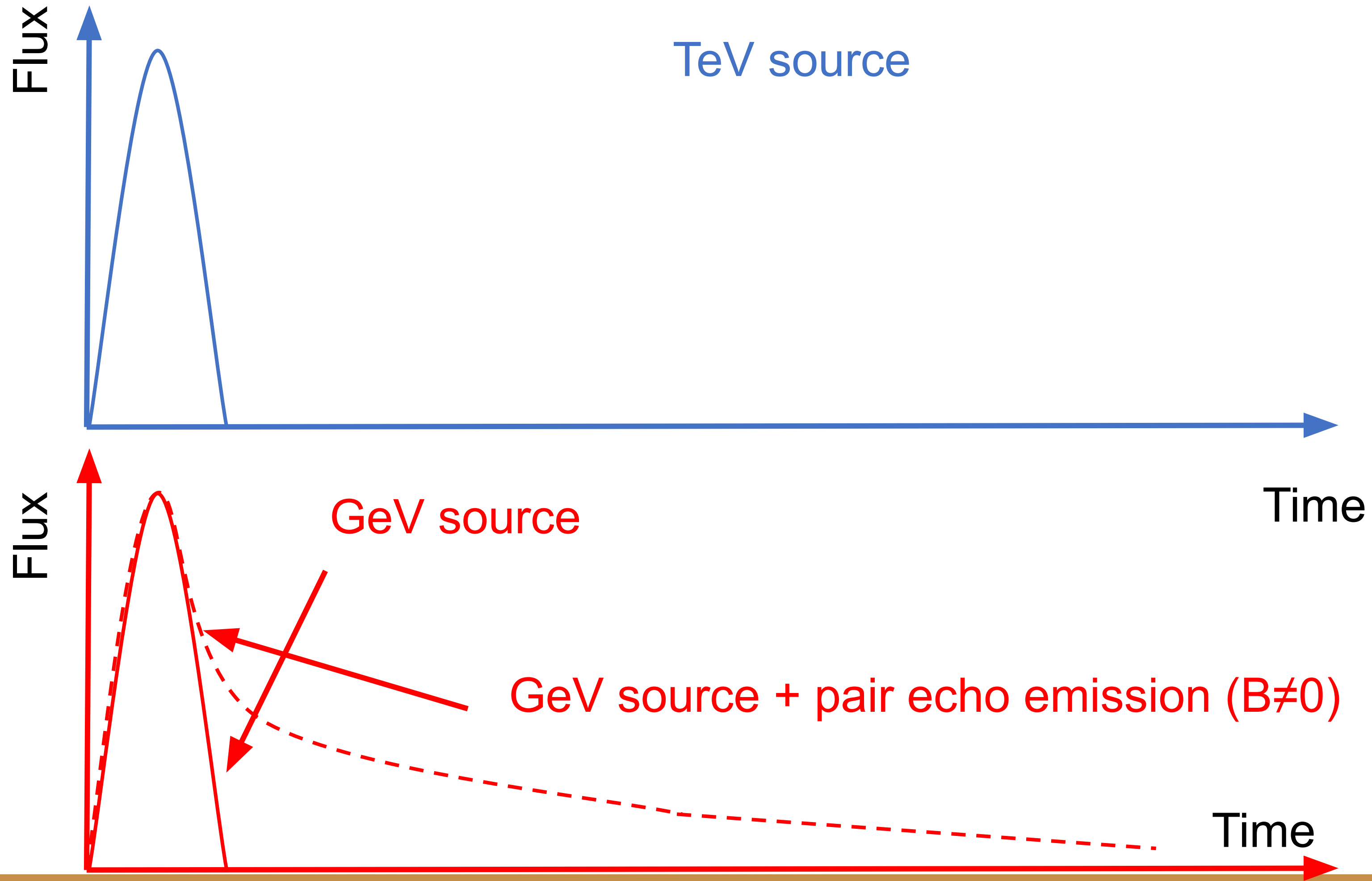
Neronov et al. 2009

Indirect detection of the IGMF



- Extended γ ray halos
- Spectral features
- **Time delayed γ-ray emission**

Search for the “pair-echo” emission

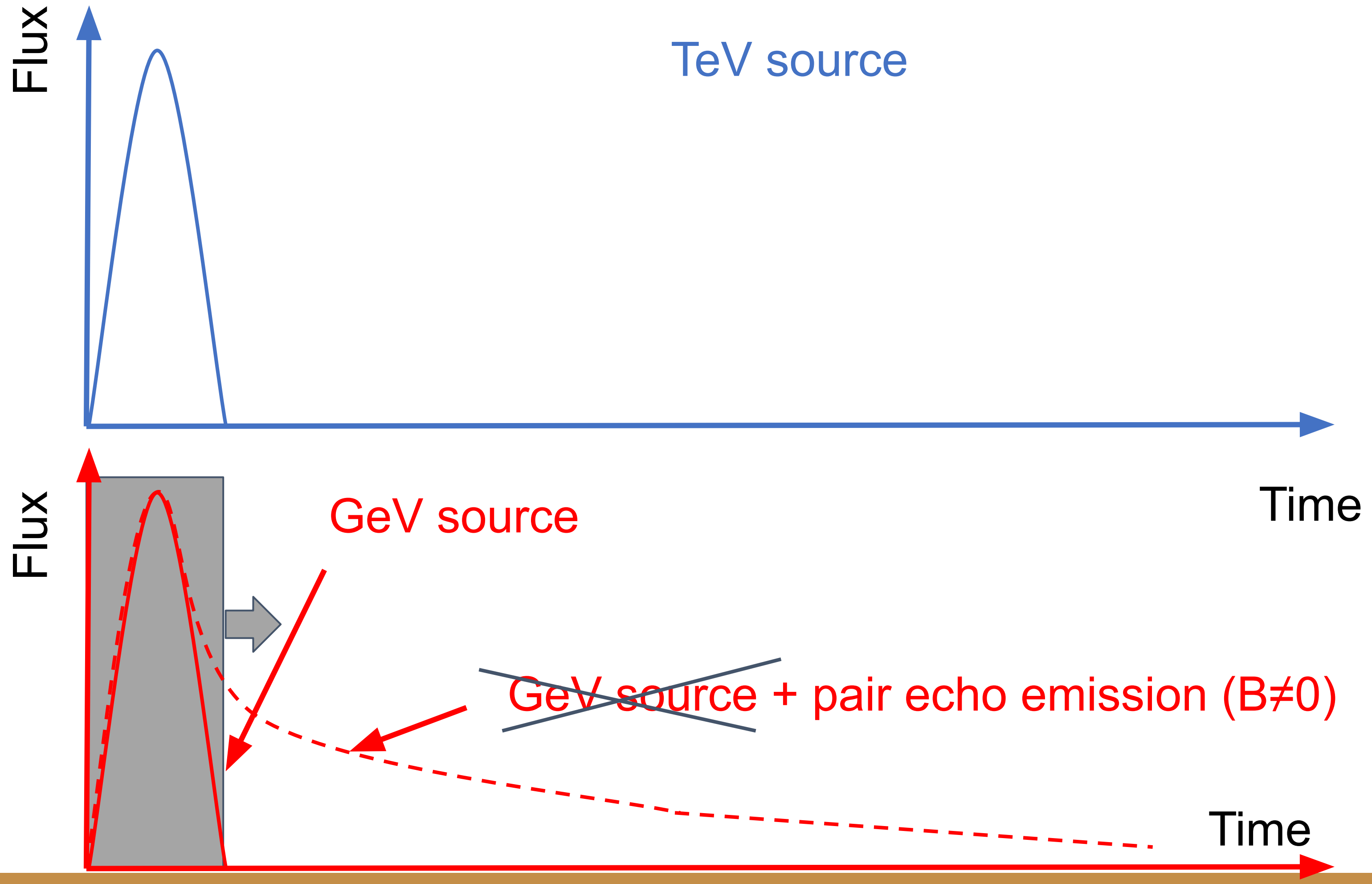


$$T_{delay} \propto E^{-5/2} B^2$$

Neronov et al. 2009

Interesting for transient events, particularly for GRB

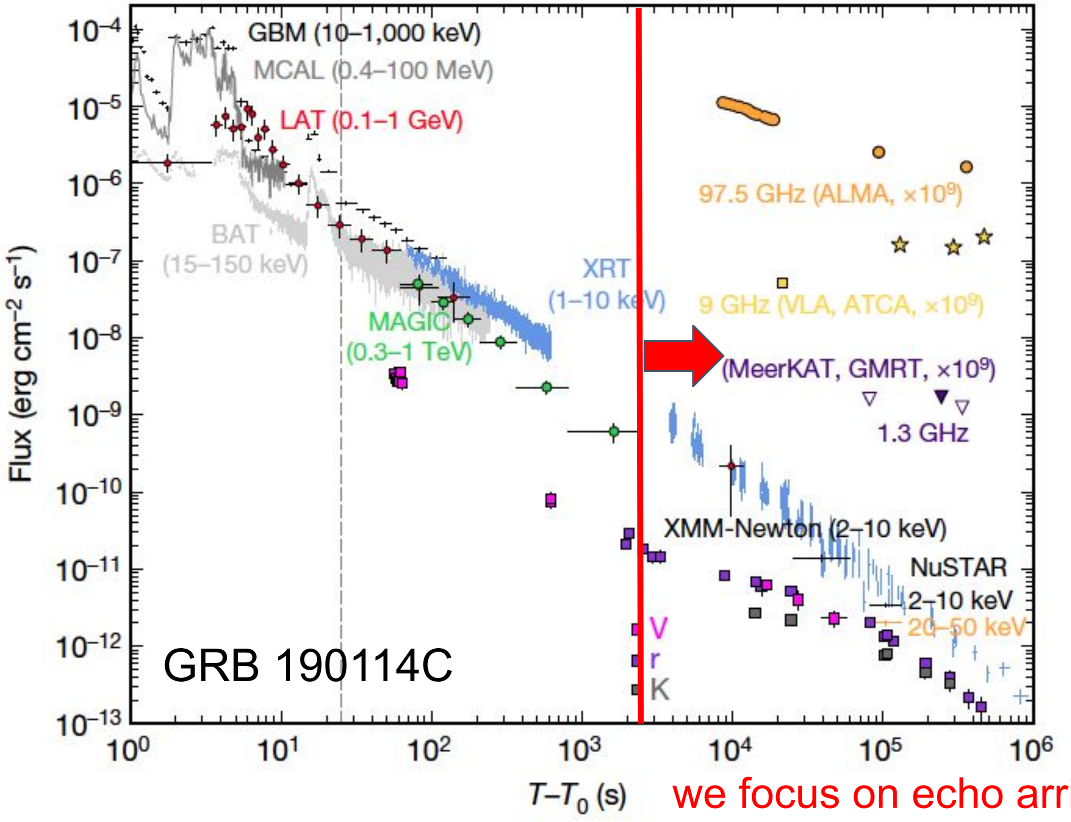
“Pair-echo” after the end of TeV afteglow emission



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

Advantage: avoid the source GeV emission

Pair-echo emission after the end of the afterglow



we focus on echo arriving in this time range

MAGIC coll. 2019

***Goal*:** we used CRPropa to compute the pair-echo SEDs when GRB TeV afterglow is not detected anymore

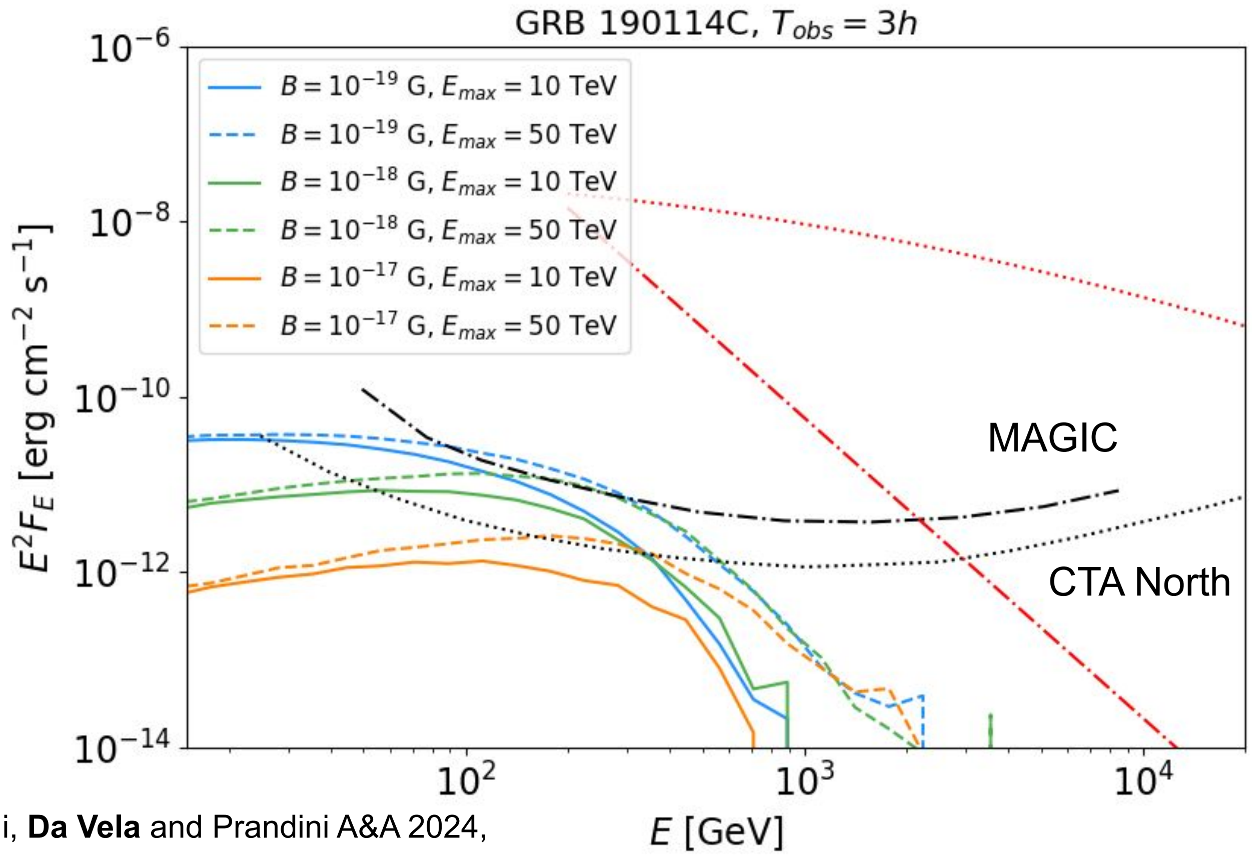
- for the case of GRB190114C (z=0.42)
- for a generic GRB190114C-like source at different distance (z=1.0 and z=0.2)
- for GRB221009A (z=0.15)
- for a generic GRB221009A-like source at larger distance (z = 1.0)

Pair-echo emission after the end of the afterglow: pair echo SEDs calculation

- Source:
  - VHE spectrum: logparabola with two different E_{max}=10, 50 TeV
- IGMF:
  - Kolmogorov turbulent spectrum
  - B_{rms}= 10^{-19} G, 10^{-18} G, 10^{-17} G
- 3 exposure times (compatible with IACTs capabilities):
  - T_{exp}= 3 h, 6 h and 9 h

Comparison of the pair-echo SEDs with MAGIC and CTA-North sensitivities

Pair-echo emission after the end of the afterglow: results

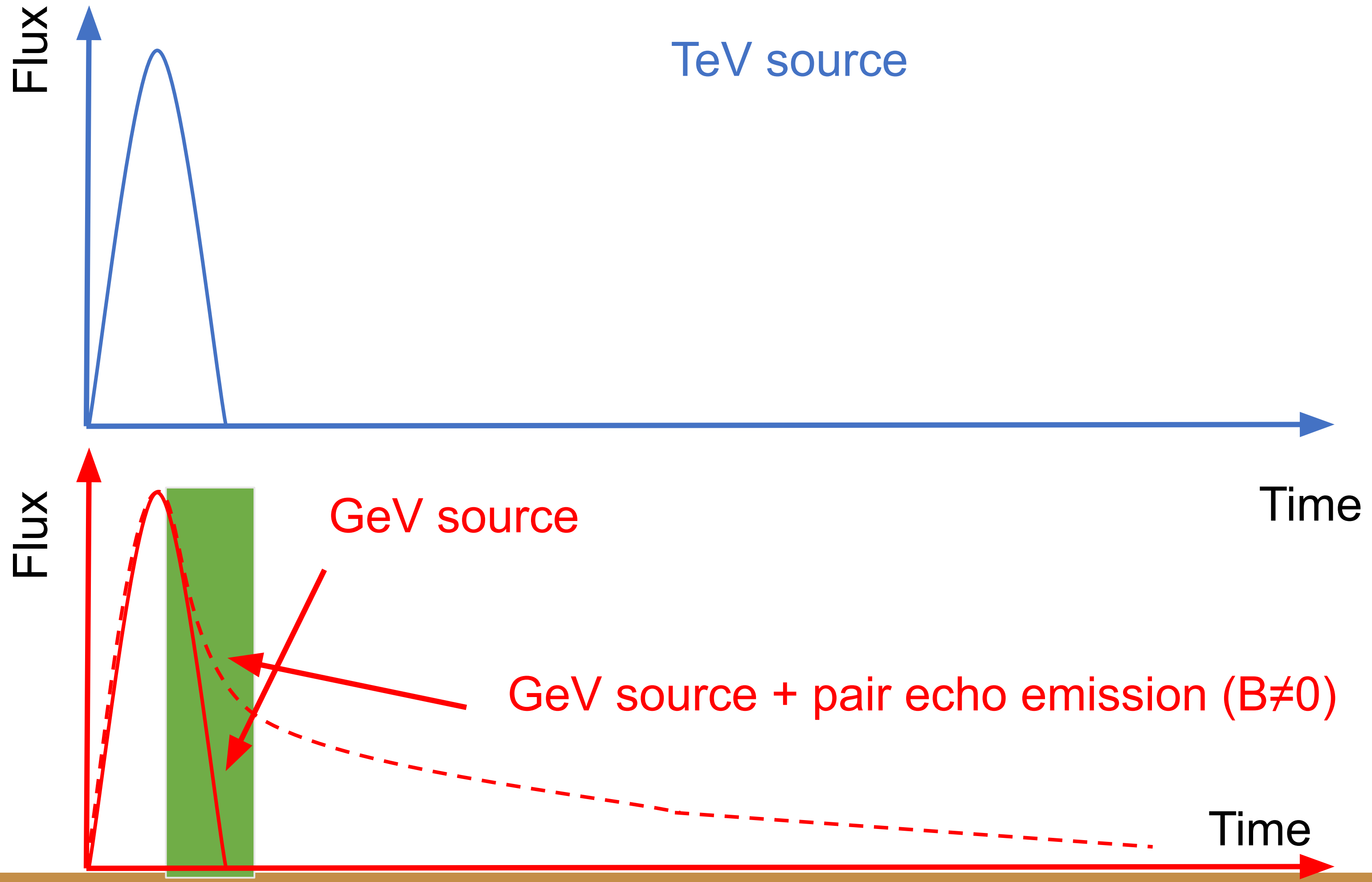


Miceli, **Da Vela** and Prandini A&A 2024,
DOI: 10.1051/0004-6361/202449305

Spectral energy distribution

- GRB 190114C (z=0.42) VHE afterglow emission
- Simulated pair-echo SEDs
- Observation time: 3 hours from T_0= 3000 s
- MAGIC and CTA-North sensitivities derived from the CTAO website and rescaled in time (~1/√T)

"Pair-echo" emission during the afterglow fading phase



- During the GRB afterglow fading phase the pair-echo emission might "compete" with the afterglow
- The GRB afterglow can vary of several order of magnitudes
- To understand whether the pair-echo emission can dominate over the afterglow a proper modeling of the cascade evolution is needed

"Pair-echo" emission during the afterglow fading phase: modeling

Convolution of the pair-echo response to an impulse in the VHE band with the variability pattern of the GRB afterglow in the same energy band

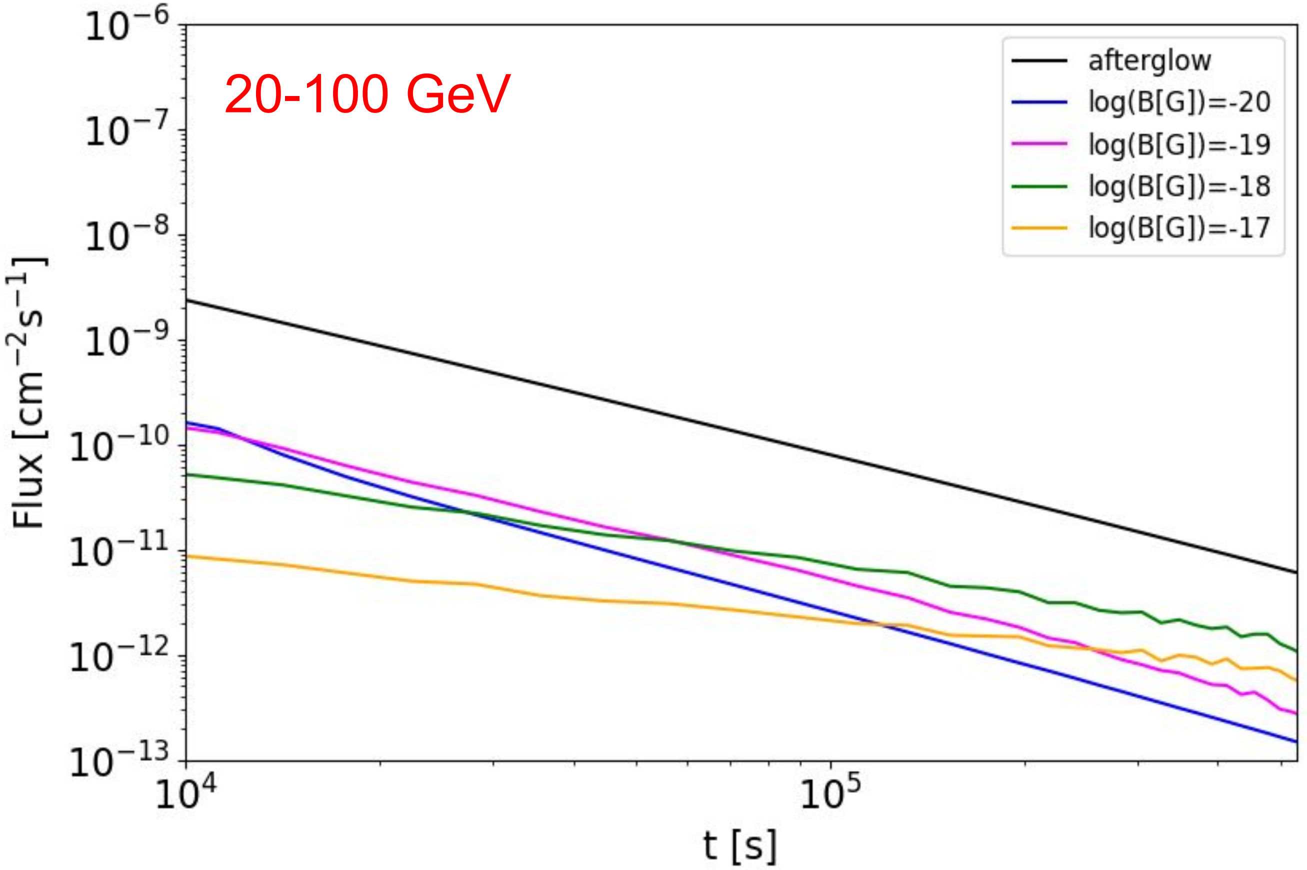
$G(E_0, E, \tau)$ → Kernel function describing the distribution of the pair-echo photons in energy and time

$$\boxed{F_c(E,t) = \int_E^{\infty} \int_0^{\infty} G(E_0, E, t-\tau, \tau) F_s(E_0, t-\tau) d\tau dE_0}$$

"Pair-echo" emission during the afterglow fading phase: pair-echo lightcurve computation

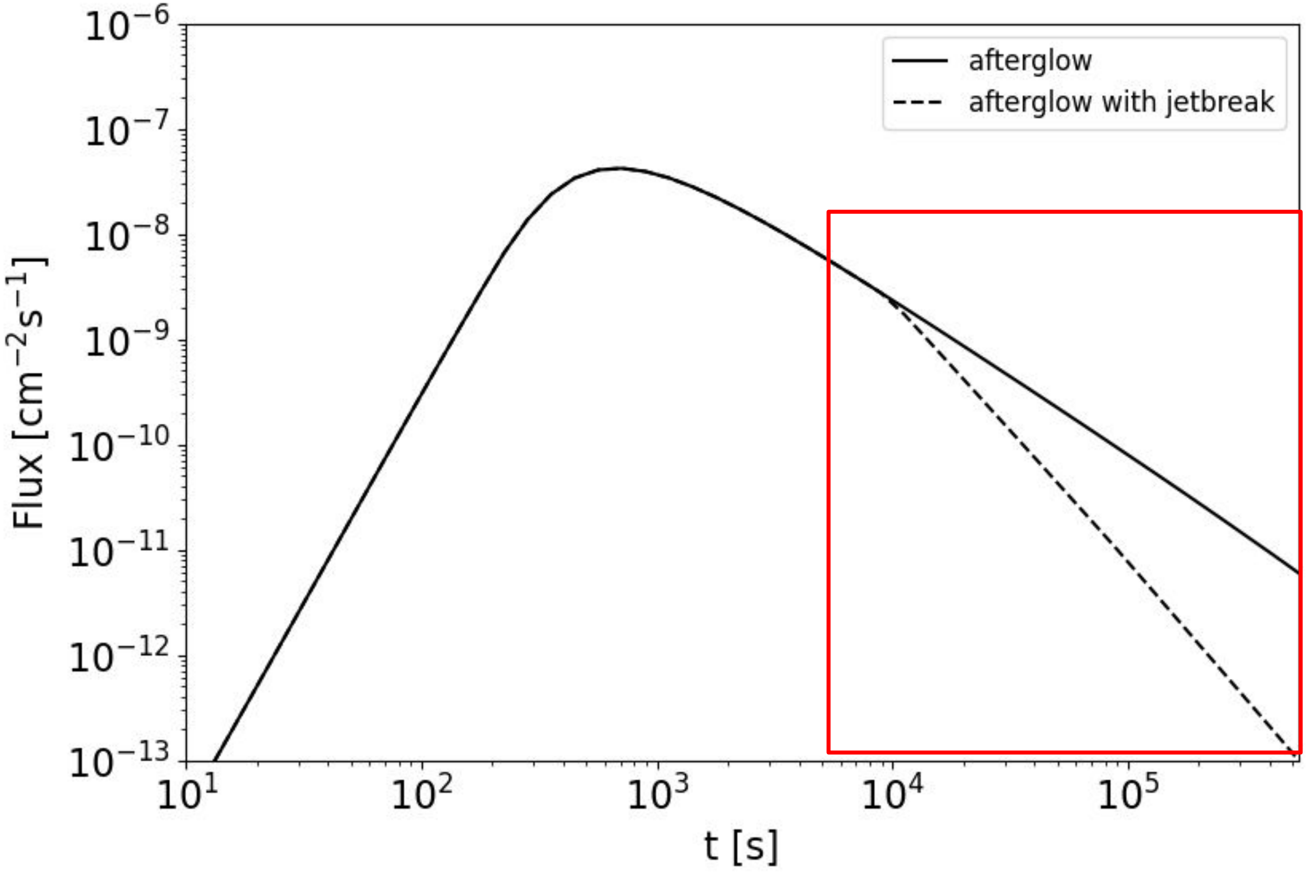
- Simulated GRB:
  - Emission model: Synchrotron Self-Compton (SSC)
  - $E_{iso} = 3\times10^{52}$ erg
  - Redshift, $z=0.47$
- Intrinsic VHE spectrum (for the simulations): we computed the average VHE spectrum over the whole time window
- We built the kernel function G for different IGMF strengths and computed the pair-echo lightcurves

“Pair-echo” emission during the afterglow fading phase: results



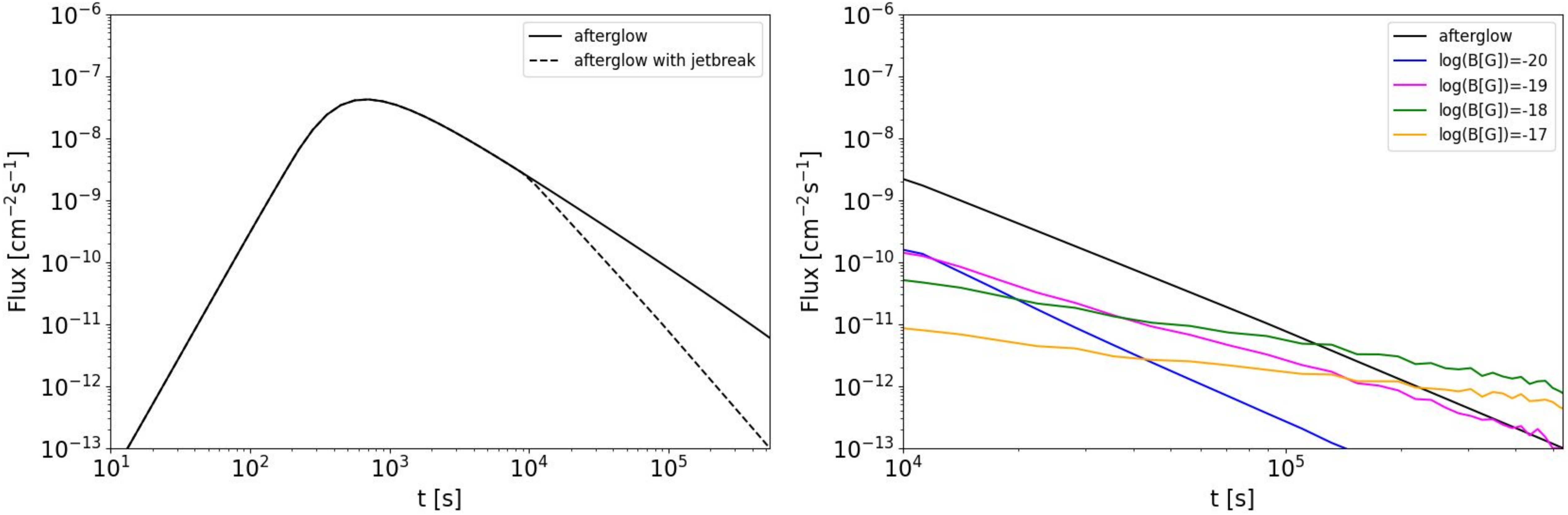
The cascade component is subdominant but…

“Pair-echo” emission during the afterglow fading phase: jetbreak

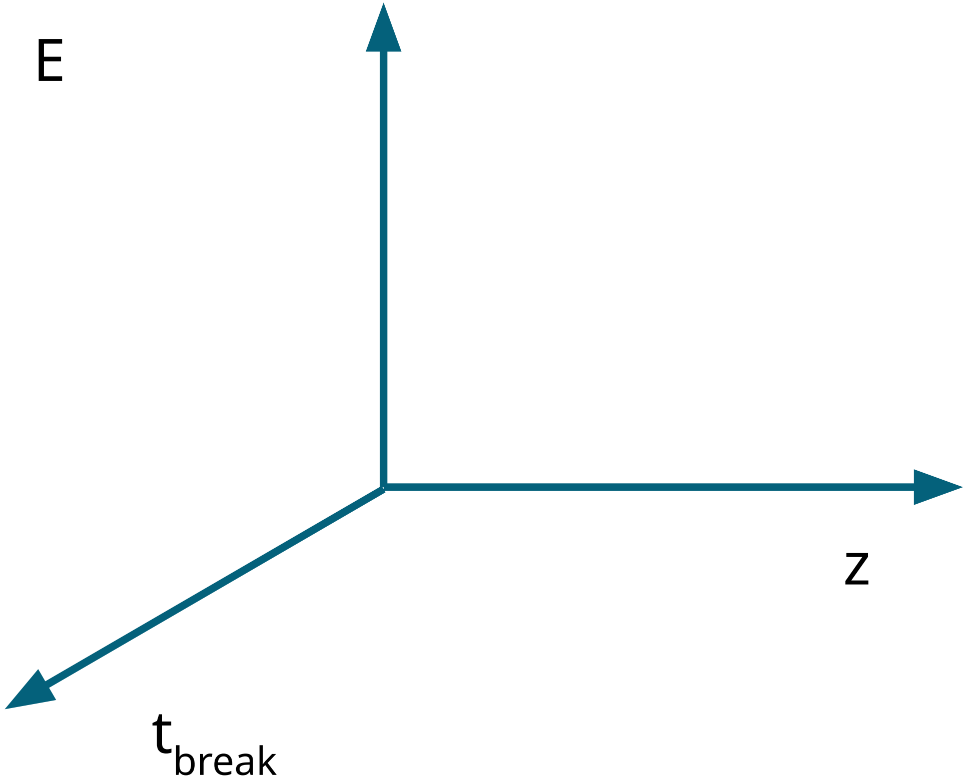


Jet break at 0.1 days
→lightcurve steepening of a factor of ~ t^{-1}

“Pair-echo” emission during the afterglow fading phase: jetbreak



"Pair-echo" emission during the afterglow fading phase: outlooks



- 3D parameters space:
  - z, E, t_{break}
- Scan of the parameters space
- What are the regions of this space for which the pair-echo becomes dominant or competitive with the afterglow?
- What are the IGMF strengths that can be constrained with the current and future instruments?

Conclusions

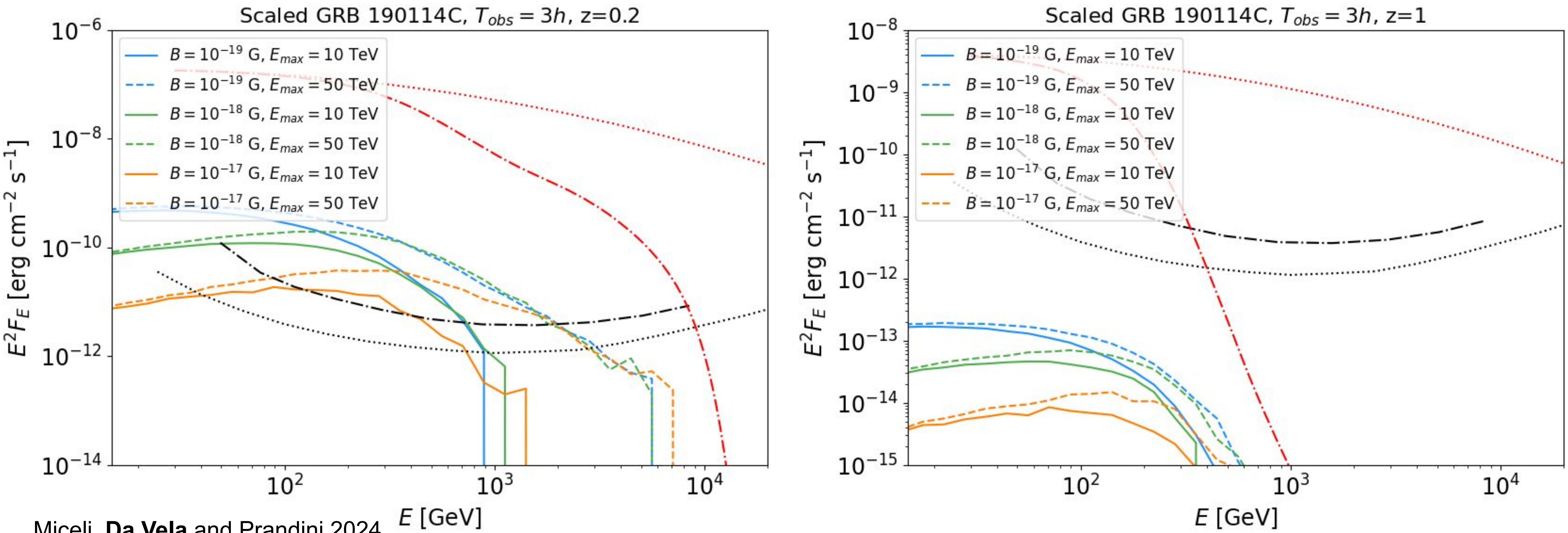
- ★ Gamma-Ray Bursts are promising sources for IGMF studies

- ★ Pair-echo emission after the end of the afterglow:
  - ○ extend the observations for at least 3 hours after GRB detection
  - ○ GRBs observations can probe IGMF strengths in the range 10^{-19} G - 10^{-17} G →competitive with AGN studies! (see Guillem Martì Devesa talk)

- ★ Pair-echo emission during the fading afterglow phase:
  - ○ it seems to be dominant (or at least competitive) with the afterglow at late times in case of jetbreak (collimated jets)
  - ○ Impact of intrinsic source features (energetics, distance and jetbreak) need to be investigated

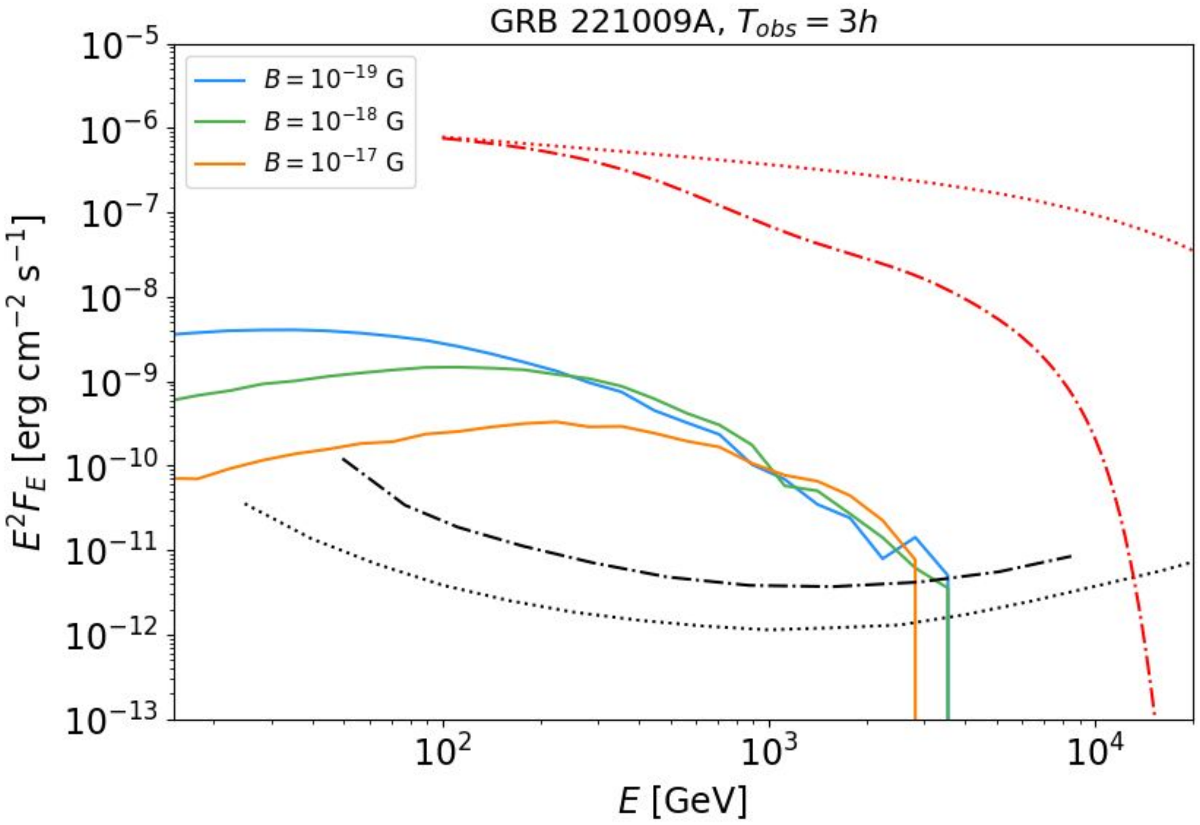
Back up

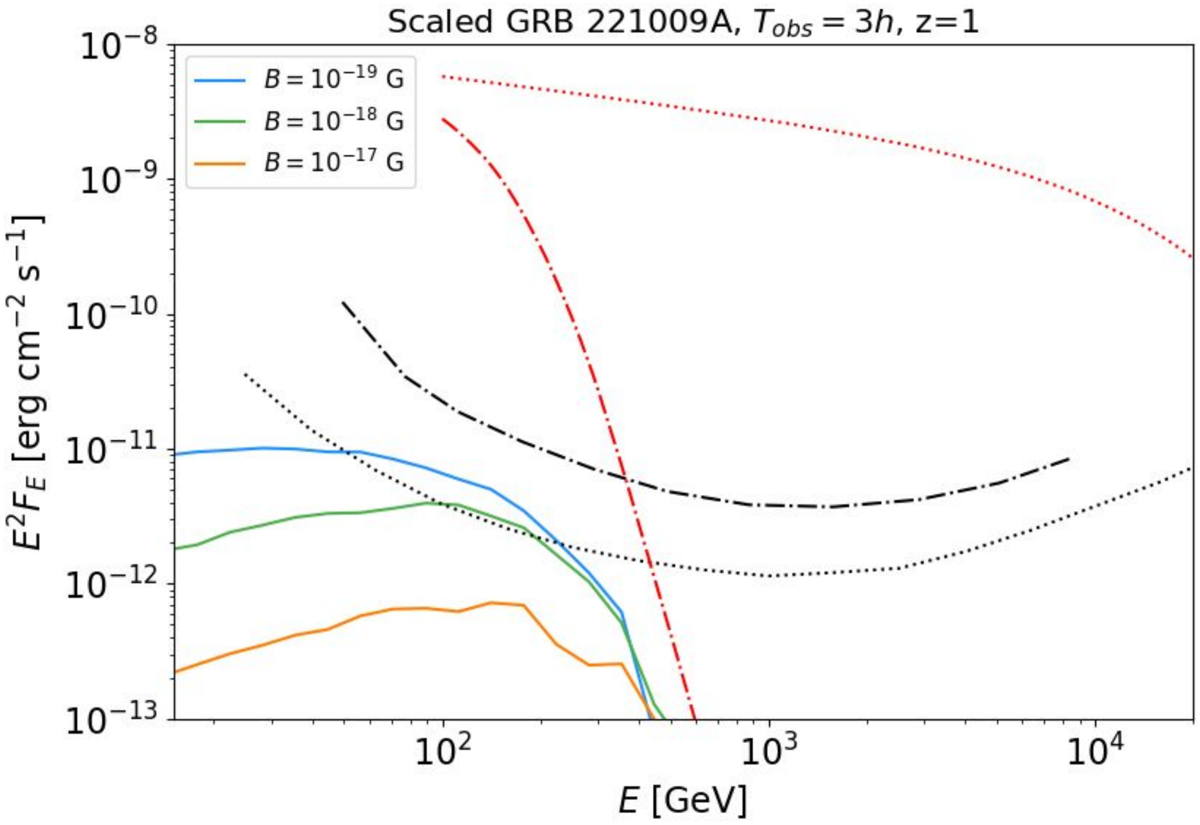
Pair-echo emission after the end of the afterglow: results



Miceli, **Da Vela** and Prandini 2024

Pair-echo emission after the end of the afterglow: results


GRB 221009A, $T_{obs} = 3h$


Scaled GRB 221009A, $T_{obs} = 3h$, z=1

Miceli, **Da Vela** and Prandini 2024