Gamma-ray echo (pair echo) from TeV sources and extragalactic magnetic fields

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generation and observation of B

magnetogenesis

- reionization
- structure formation
- first stars
- primordial fluctuations
- phase transition
- inflation

→

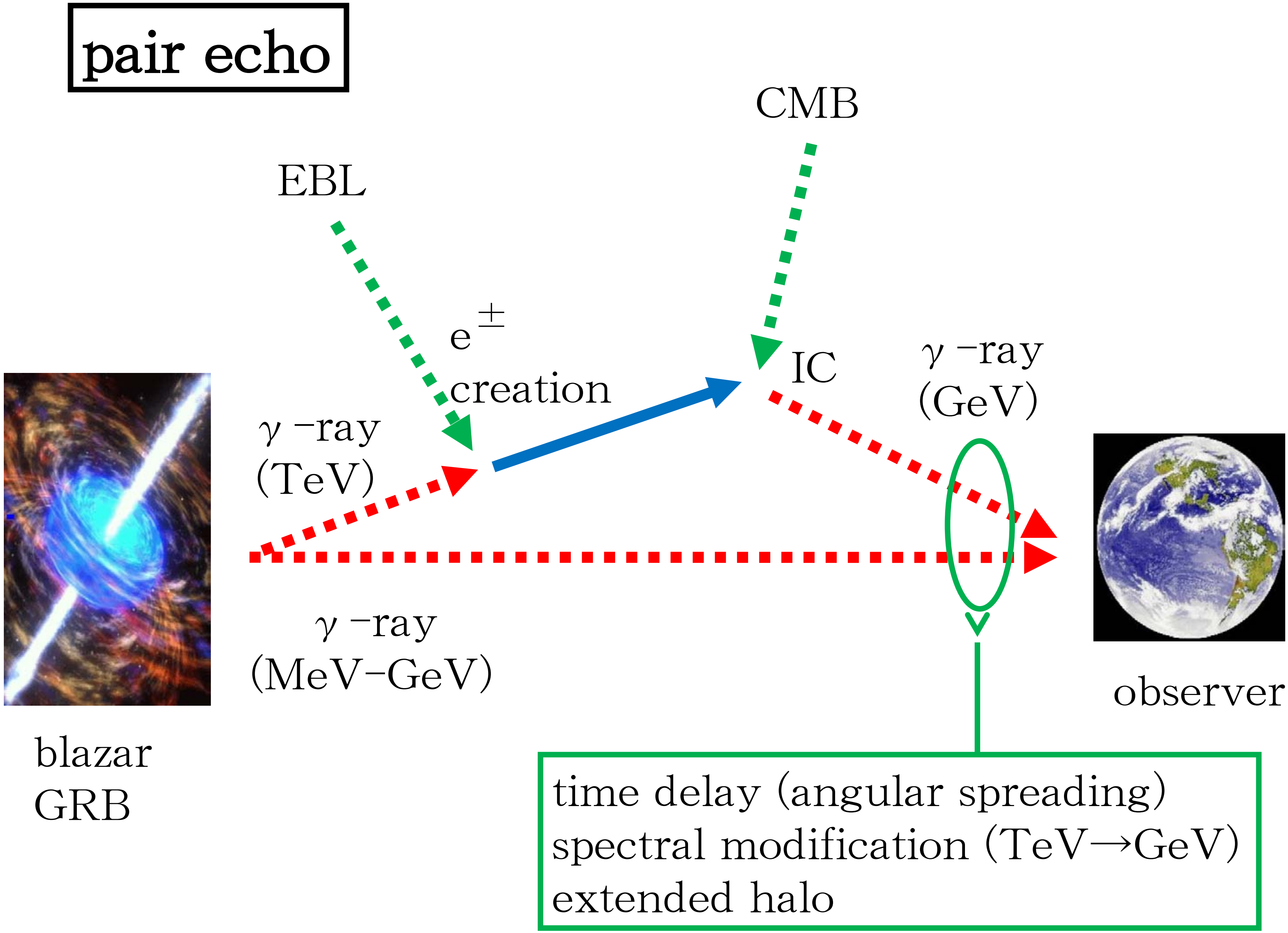
- B as a remnant
- probe early universe through B
- preserved in voids
- tiny in general ($10^{-25} \sim 10^{-15}$ G)

observation

- Faraday rotation
- CMB anisotropy

→ sensitivity $\sim 10^{-9}$ G

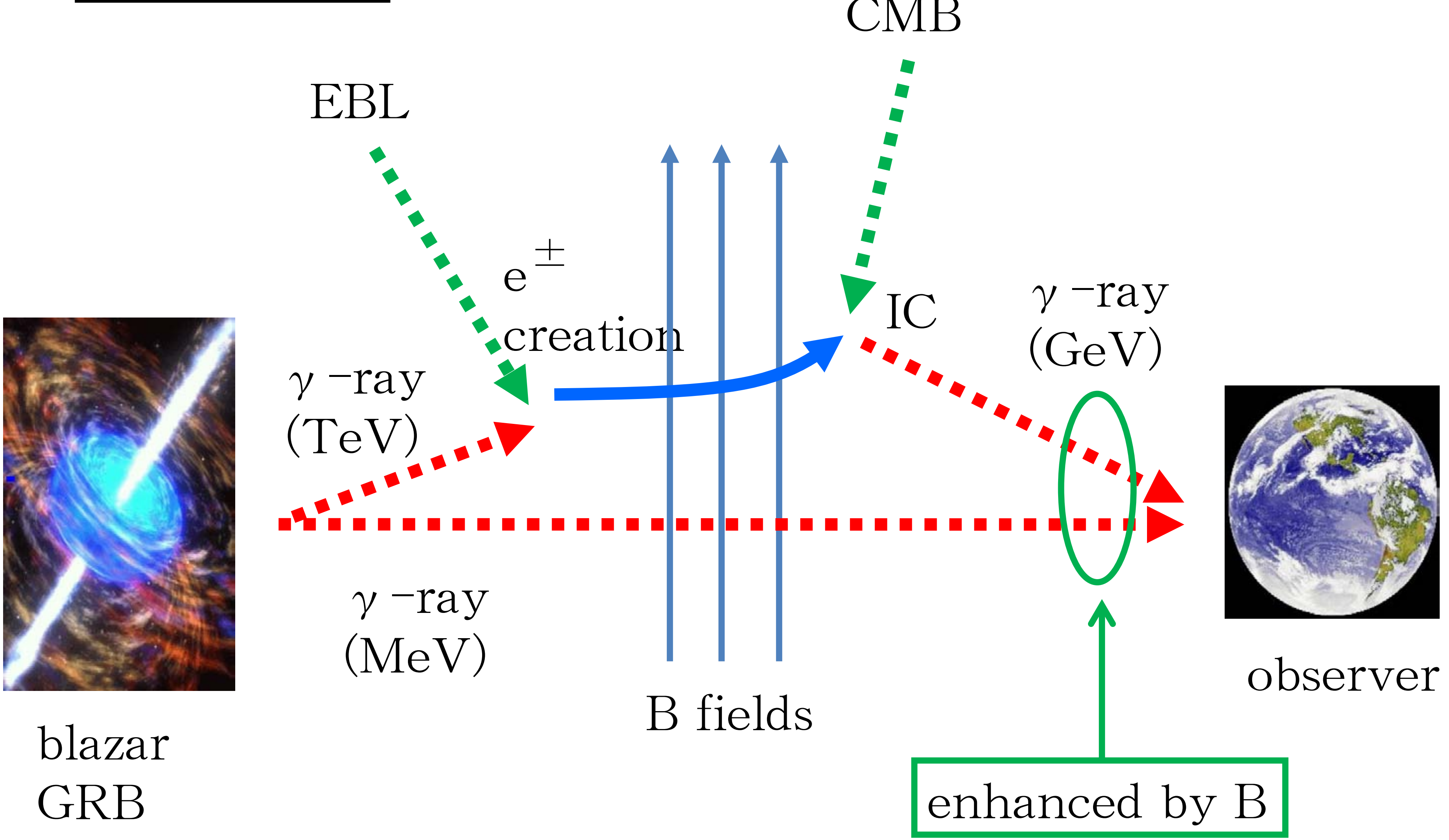
Secondary gamma-rays (pair echo) from blazars and GRBs can be used to measure tiny B.



pair echo
EBL
CMB
e±
creation
IC
γ −ray
(GeV)
γ −ray
(TeV)
γ −ray
(MeV−GeV)
blazar
GRB
observer
time delay (angular spreading)
spectral modification (TeV→GeV)
extended halo

pair echo

Plaga (1995), Dai & Lu (2002), Wang et al. (2004)
Razzaque et al. (2004), Ando (2004), KT+ (2008, 2009, 2010)



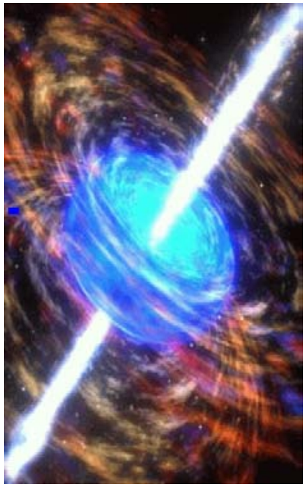
characteristic scales

EBL

$$E_{\rm IR} = 0.1\,{\rm eV}\left(\frac{E_\gamma}{1\,{\rm TeV}}\right)^{-1}$$

CMB

$$E_{\rm echo} = 0.6\,{\rm GeV}\left(\frac{E_\gamma}{1\,{\rm TeV}}\right)^{2}$$



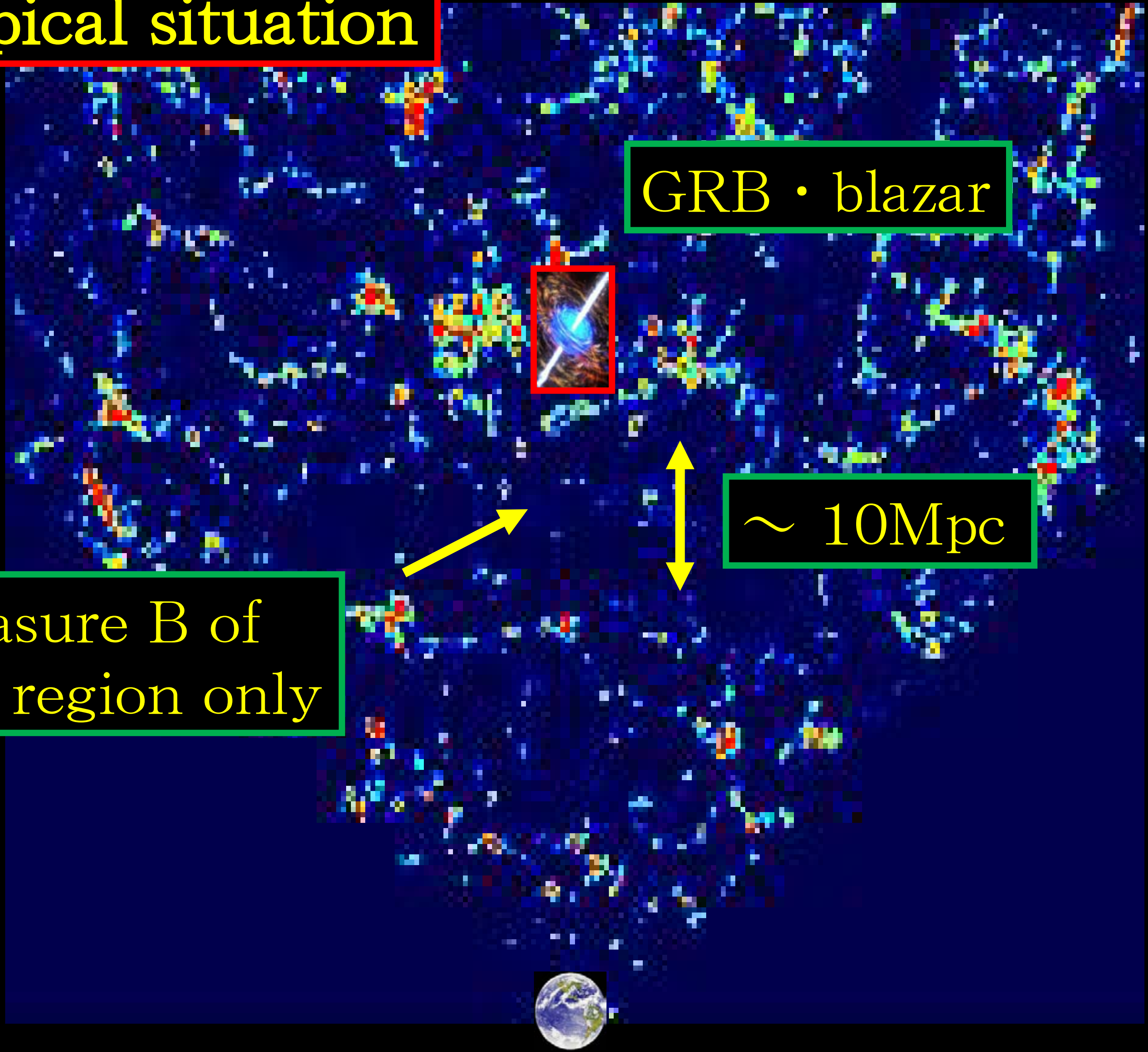
$$E_\gamma = 1\,{\rm TeV}$$

$$\lambda_{\rm IC} = 0.4\,{\rm Mpc}\left(\frac{E_\gamma}{1\,{\rm TeV}}\right)^{-1}$$

$$\lambda_{\gamma\gamma} = 20\,{\rm Mpc}\left(\frac{n_{\rm IR}}{0.1\,{\rm cm}^{-3}}\right)^{-1}$$

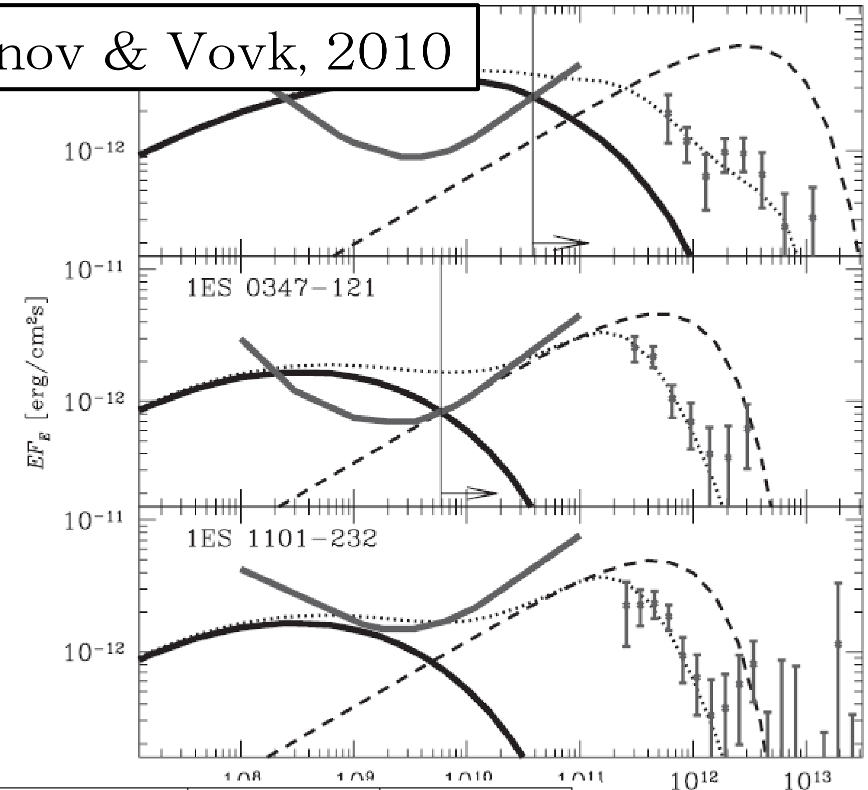
$$\Delta t_B = 0.5\,{\rm day}\left(\frac{E_{\rm delay}}{1\,{\rm GeV}}\right)^{-2}\left(\frac{B}{10^{-20}\,{\rm G}}\right)^{2}$$

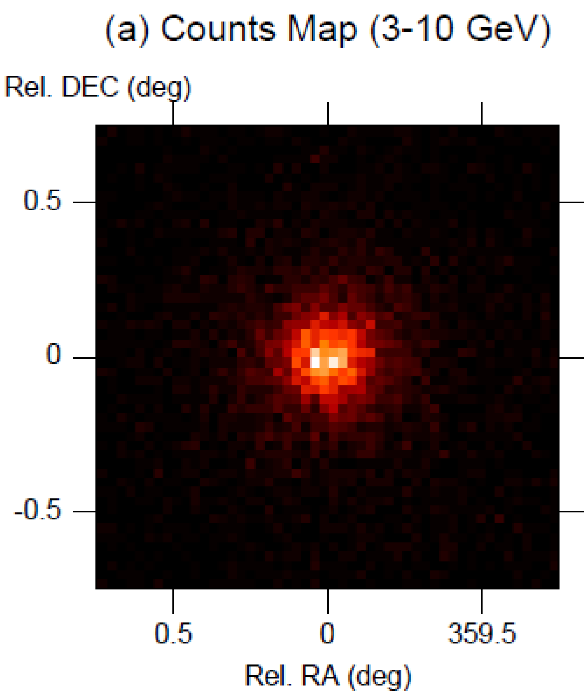
typical situation



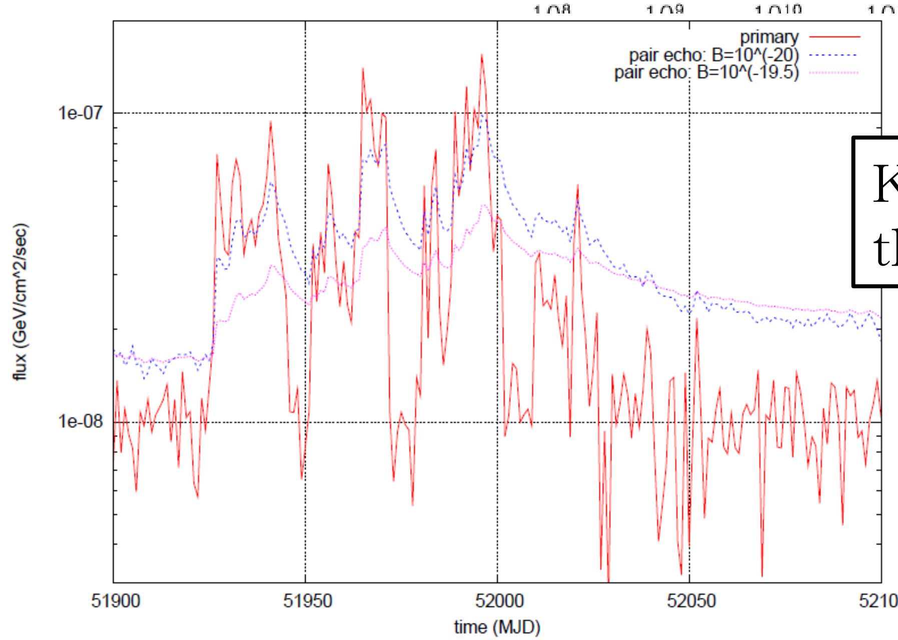
3 approaches

1. spectral modification
2. extended halo
3. lightcurve (time delay)





Ando & Kusenko, 2010



KT et al., this talk

comparison

	spectral modification	extended halo	time delay
target	blazar (quiescent)	blazar (quiescent)	blazar flare GRB
sensitivity	10^{-20}– 10^{-14}G	10^{-16}– 10^{-14}G	10^{-20}– 10^{-16}G
advantage	known target	known target	no assumption on past TeV emission
disadvantage	assumption on past TeV emission	*PSF subtlety *assumption on past TeV emission	*transient *confusion with other components

GRB and TeV blazar

GRB
- TeV emission is theoretically natural
  but has not been observed due to the sensitivity
  and mobility of the current TeV telescopes.
- prompt emission and afterglow

TeV blazar
- TeV emission is already observed.
- lightcurve is complicated (flare and quiescent emission)

Let’s start with GRBs.

GRB①: pair echo spectrum

KT+, 08, 09

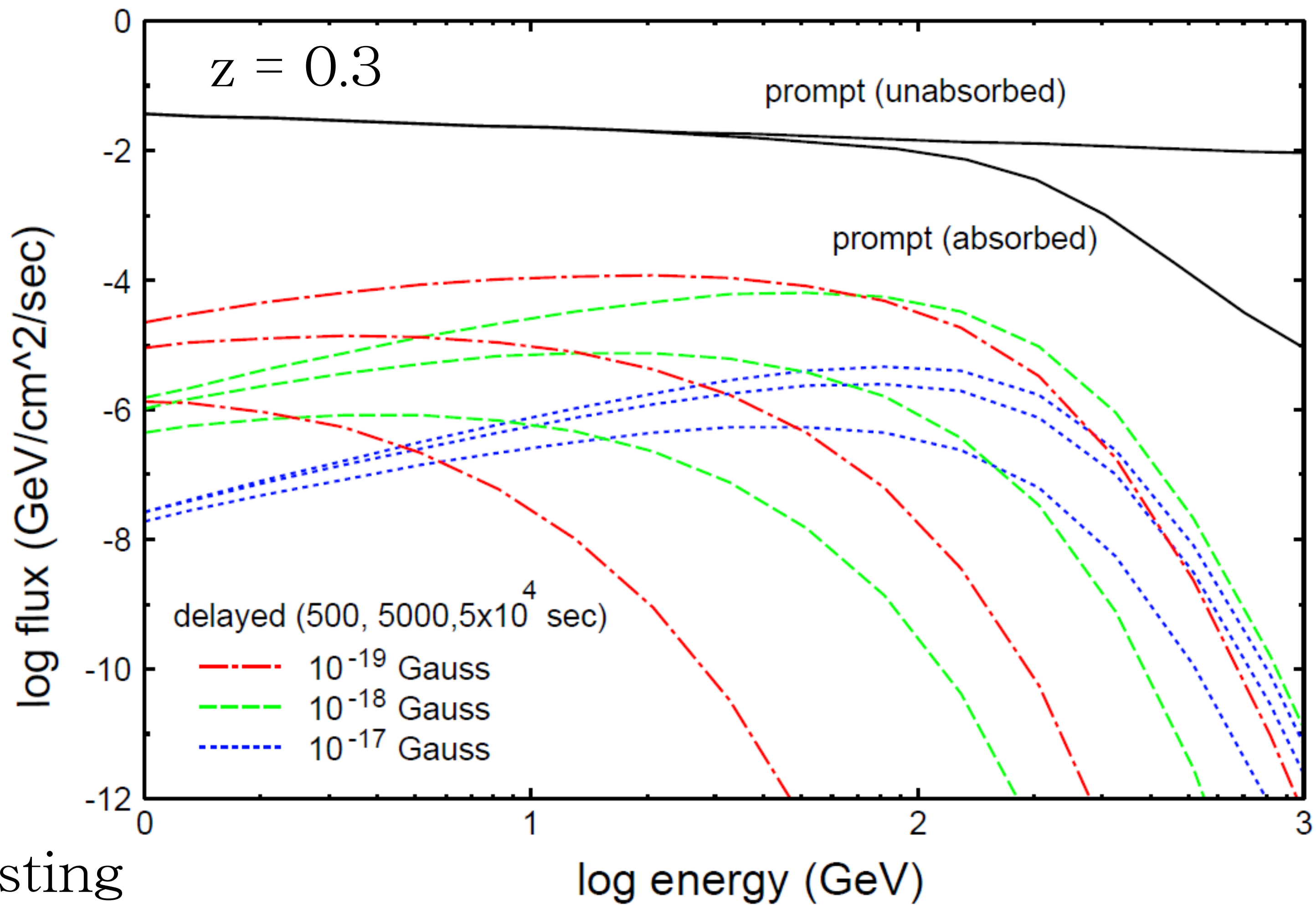
$$dN_\gamma/dE_\gamma \propto E_\gamma^{-2.2}, \text{ for } 0.1 \text{ TeV} < E_\gamma < E_{\rm cut} = 10 \text{ TeV}$$

$$E^{\rm iso}_{\gamma,[0.1,10]} = 3 \times 10^{53} \text{ erg}$$

Pair echo appears after prompt emission disappears.

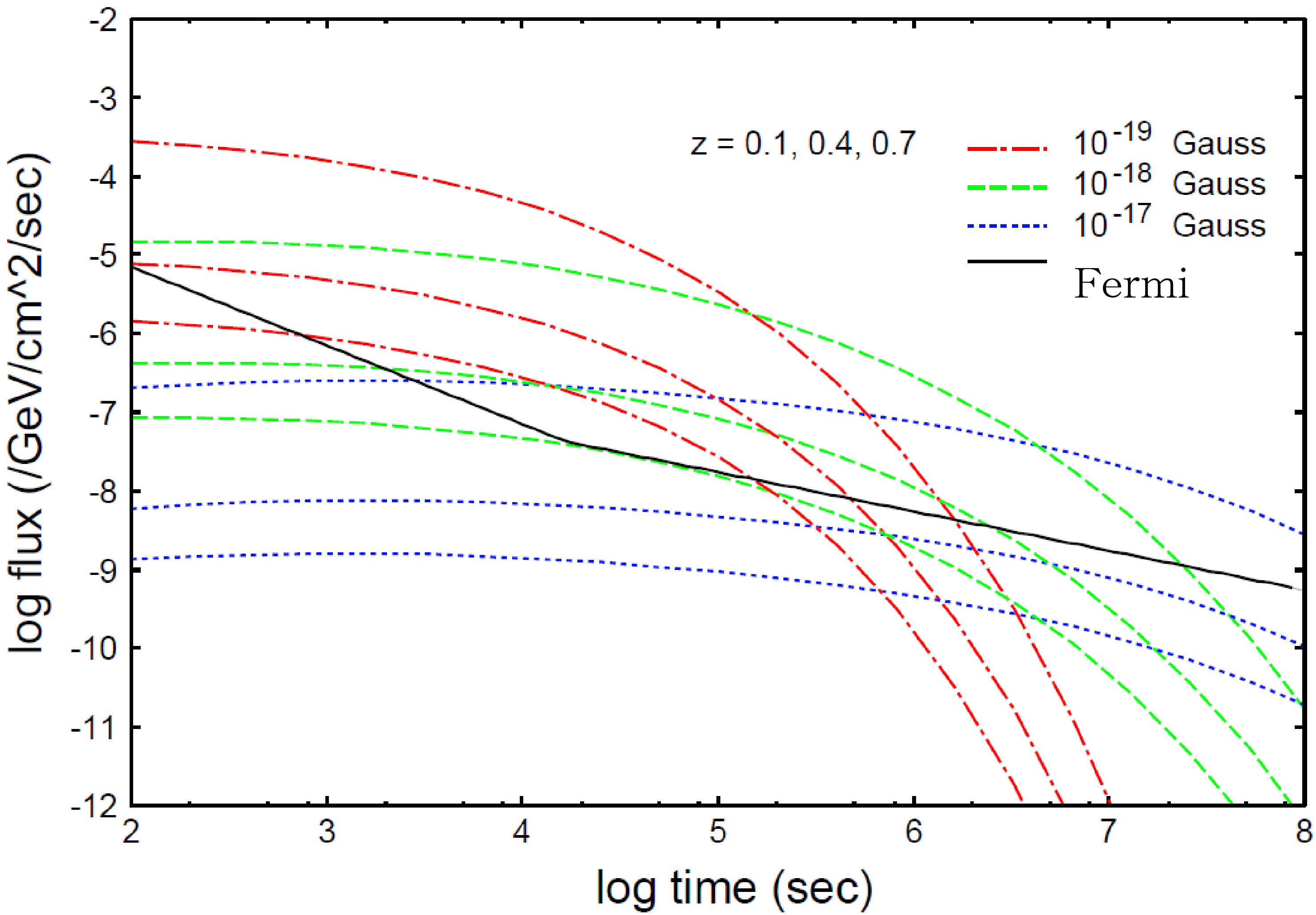
High-energy echo becomes dim earlier.

Large B
=> small flux
but long lasting



GRB②: pair echo lightcurve

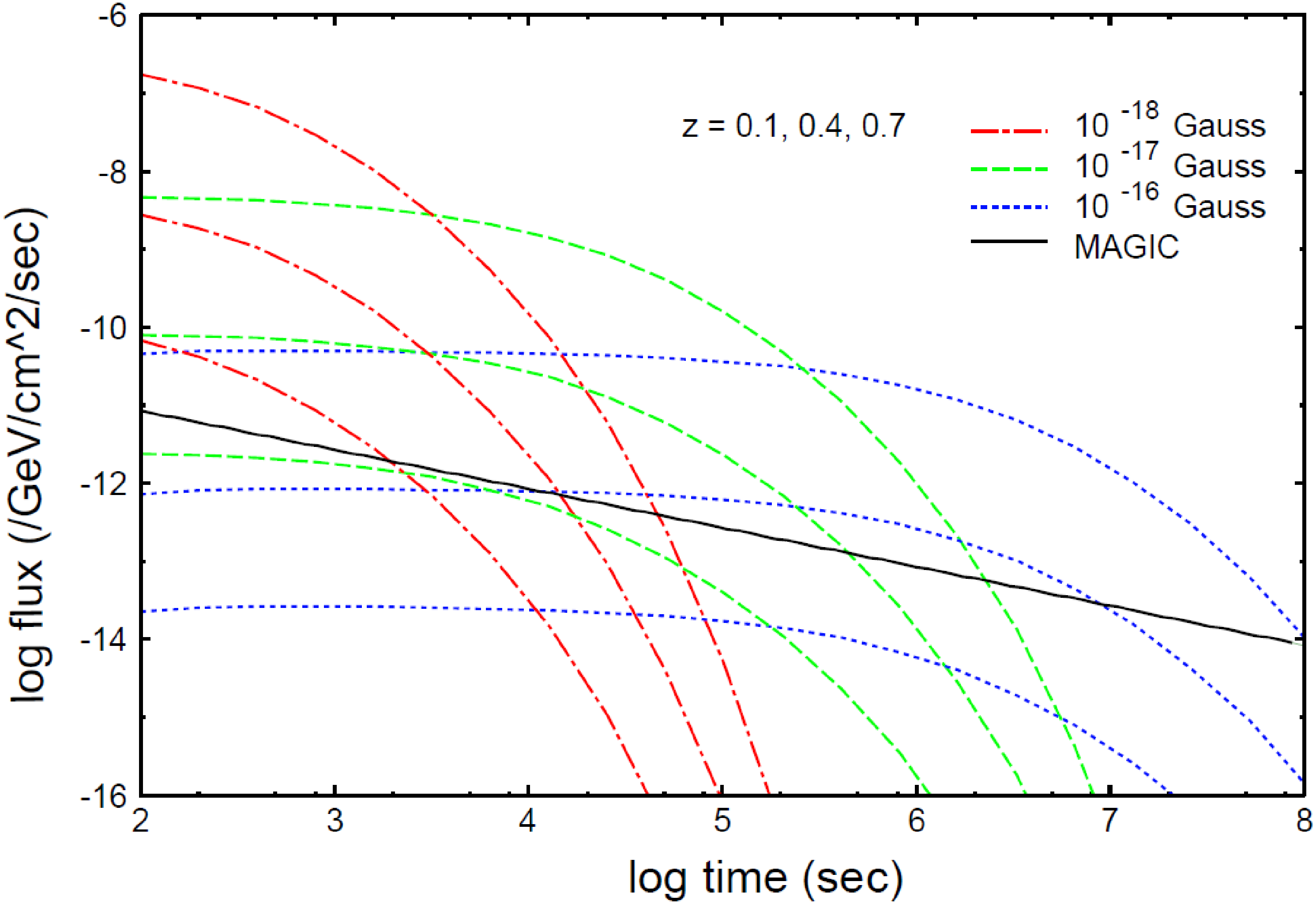
lightcurve (@1GeV)
stronger B => dimmer and longer-lasting pair echo



GRB③: pair echo lightcurve

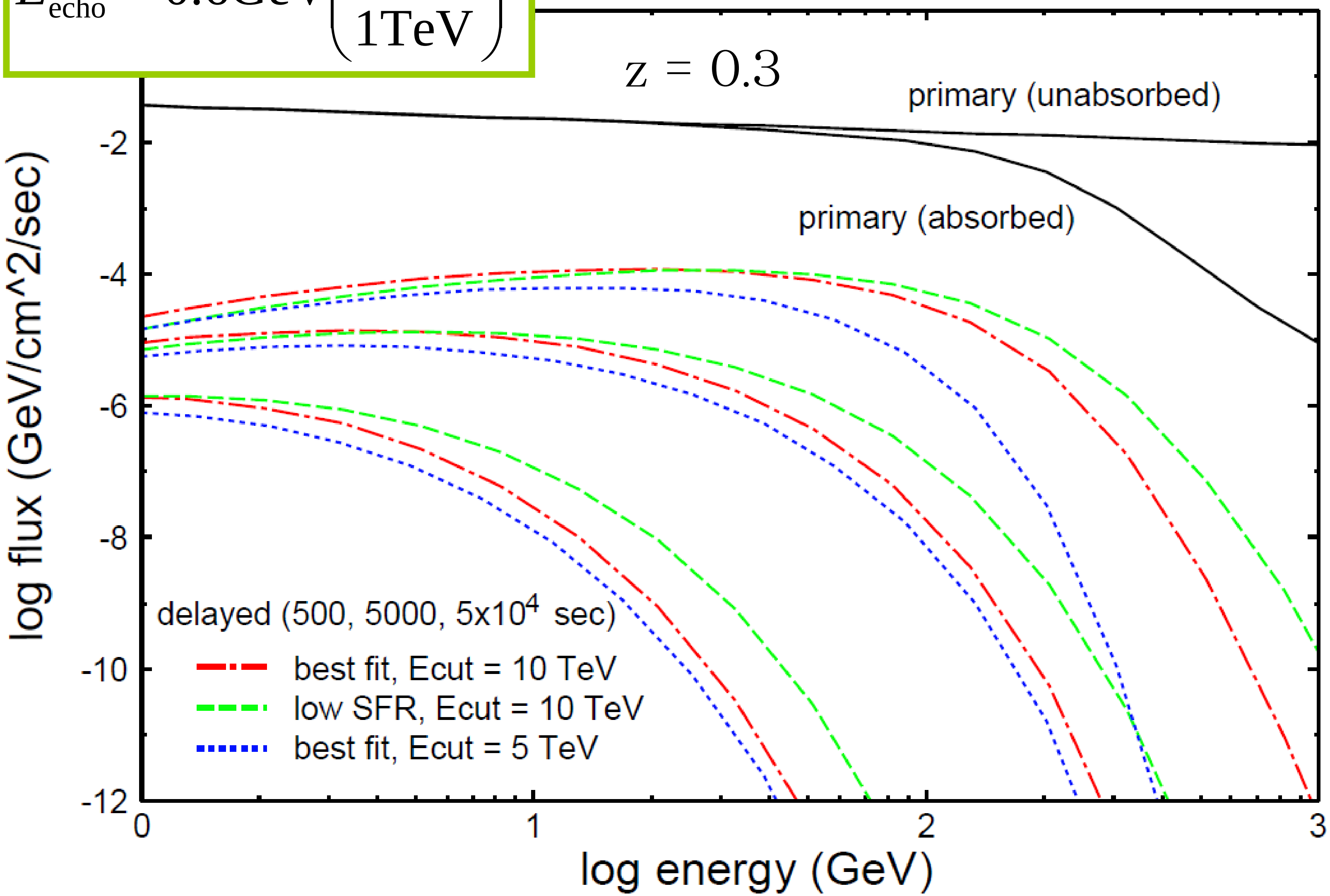
lightcurve (@100GeV)

stronger B => dimmer and longer-lasting pair echo



GRB④: dependence on cutoff and EBL

$$E_{\rm echo} = 0.6\,{\rm GeV}\left(\frac{E_\gamma}{1\,{\rm TeV}}\right)^2$$



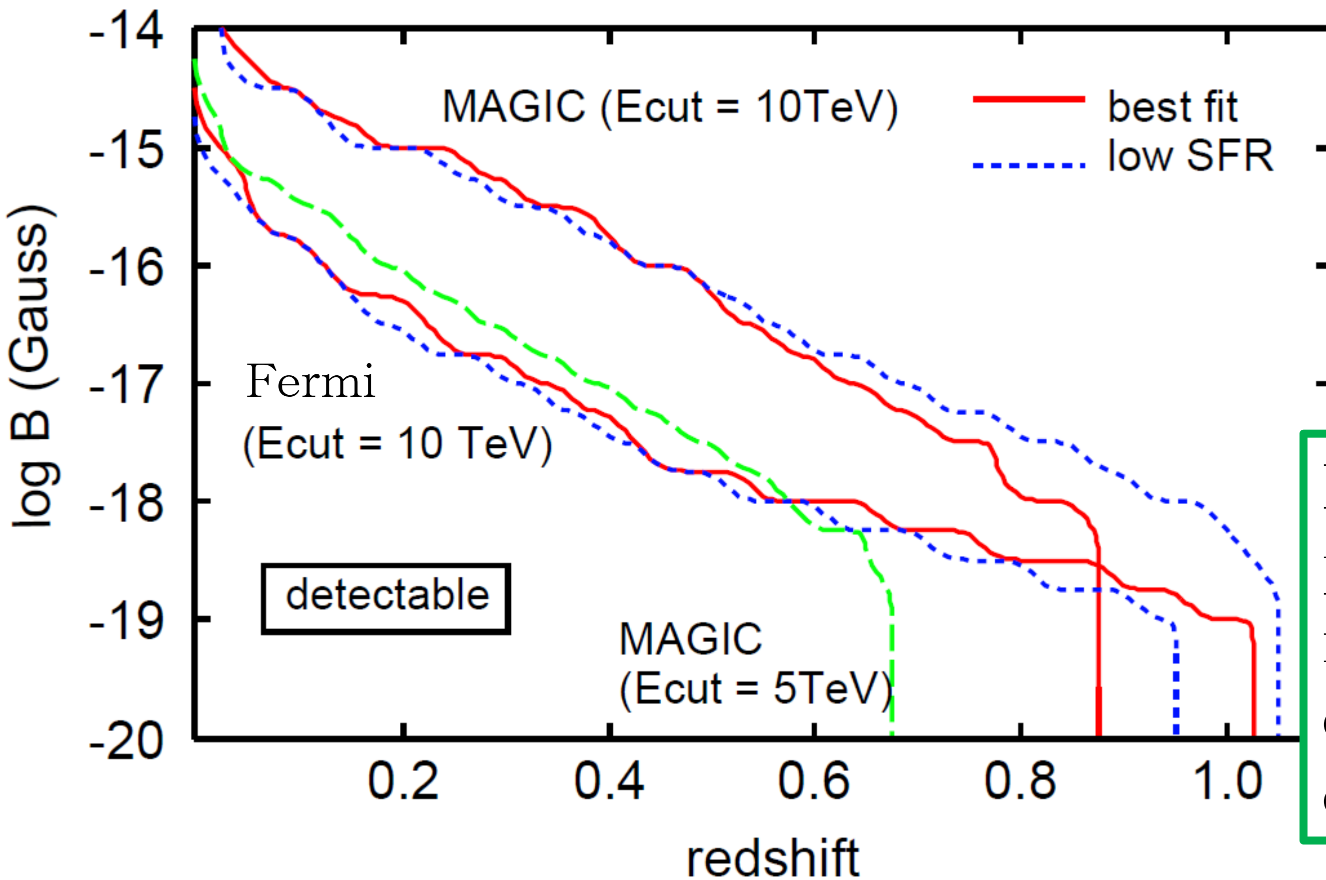
detectability of pair echo

$$dN_\gamma/dE_\gamma \propto E_\gamma^{-2.2}, \text{ for } 0.1 \text{ TeV} < E_\gamma < E_{\rm cut} = 10 \text{ TeV}$$

$$E^{\rm iso}_{\gamma,[0.1,10]} = 3 \times 10^{53} \text{ erg}$$

preferable condition:

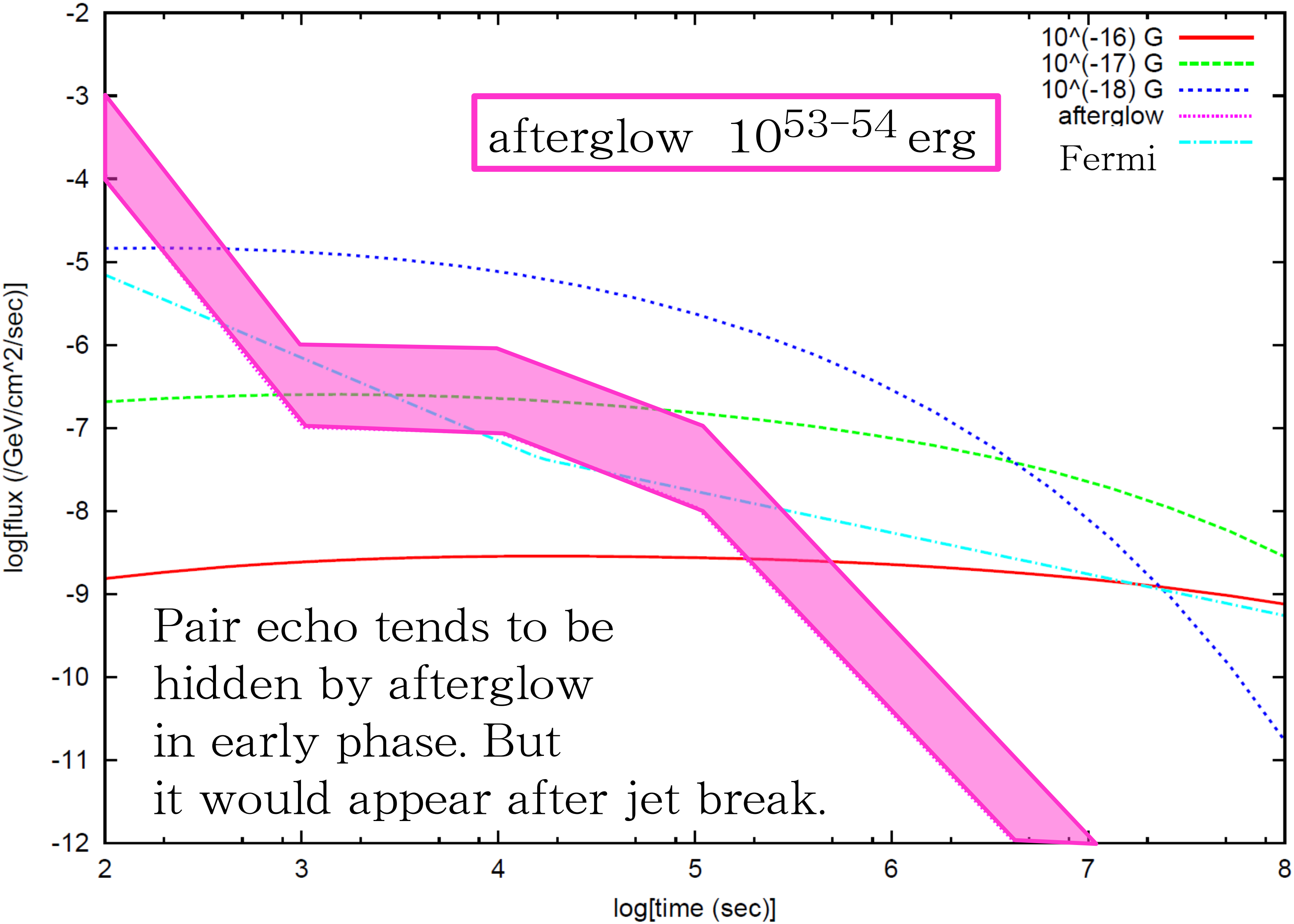
near, weak B, large cutoff energy, afterglow



for CTA,
z ∼ several

For very weak B, pair echo has no information on B, even if it is observed.

afterglow

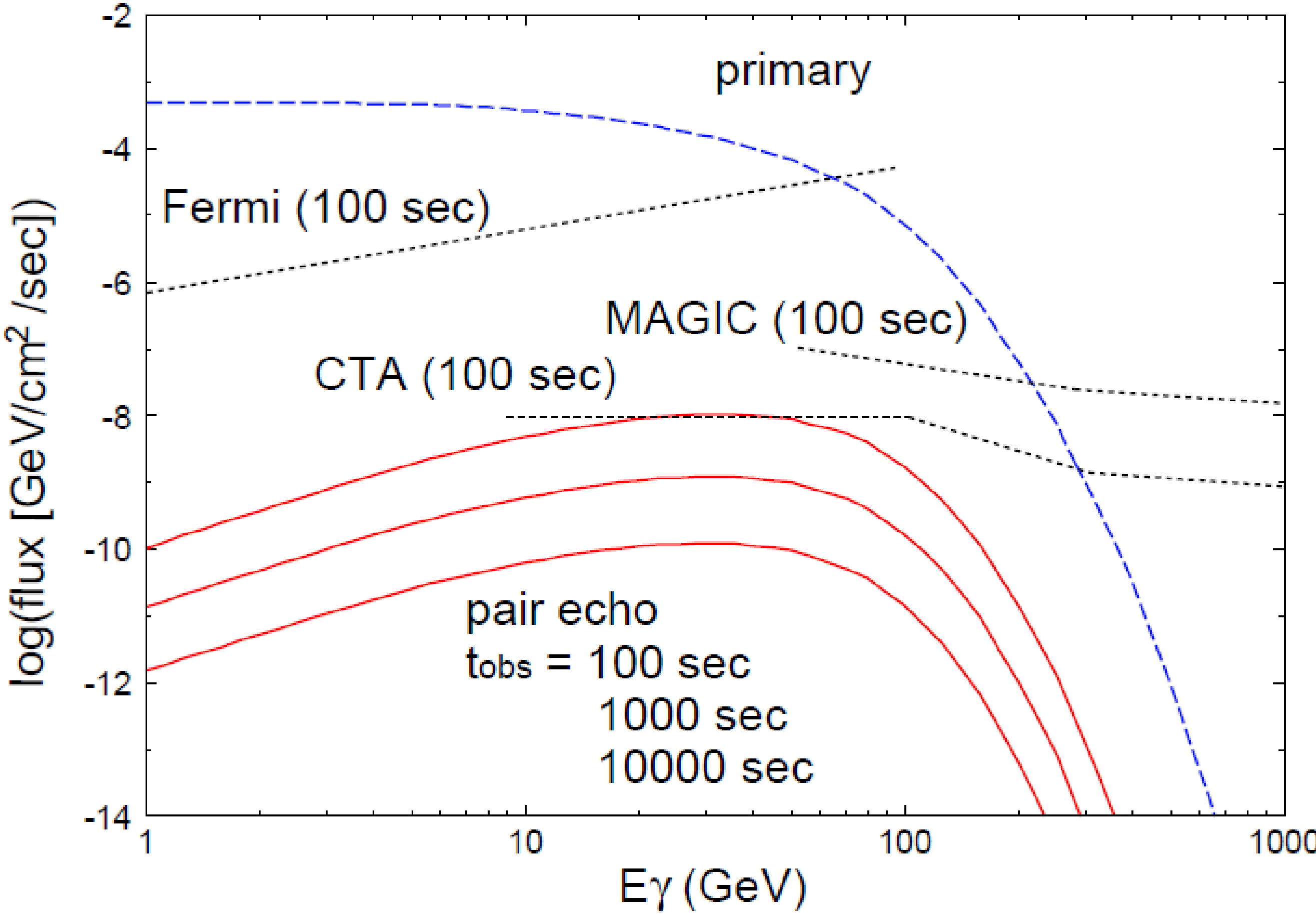

afterglow 10^{53-54} erg
10^(-16) G
10^(-17) G
10^(-18) G
afterglow
Fermi
Pair echo tends to be hidden by afterglow in early phase. But it would appear after jet break.
log[flux (/GeV/cm^2/sec)]
log[time (sec)]
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
2
3
4
5
6
7
8

pair echo from high-z GRB

KT+, 10

high-z GRB (z > 10)

- purely primordial B
- target of pair annihilation is only CMB



$z = 10$

$E_{tot} = 10^{55}$ erg

$B = 10^{-15}$ G

Challenging even for CTA.

GRB and TeV blazar

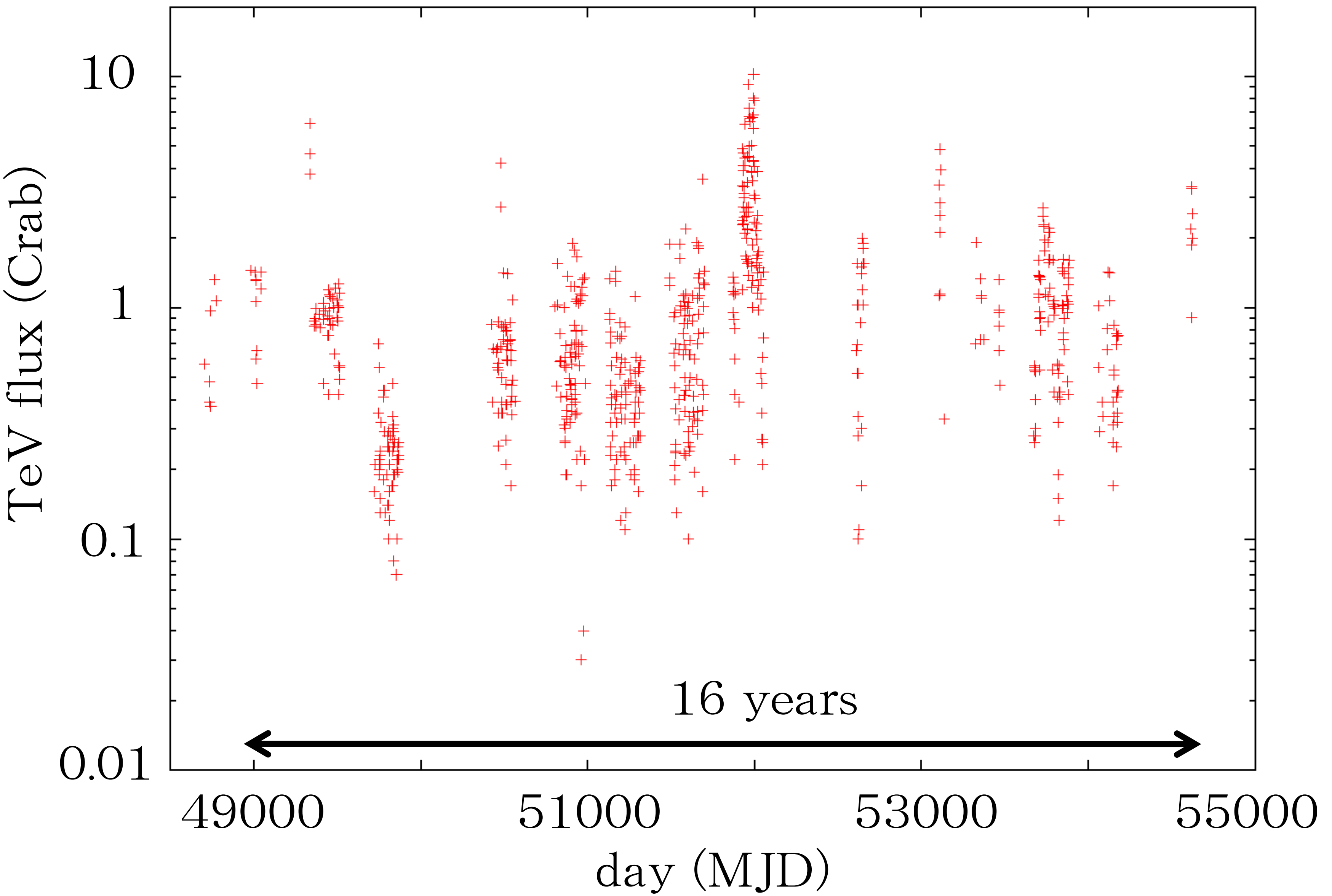
GRB is a simple example to consider.
But we should be lucky to observe TeV emission of GRB.
We have to wait...

We already know TeV emission of blazars.
This is more promising observationally.

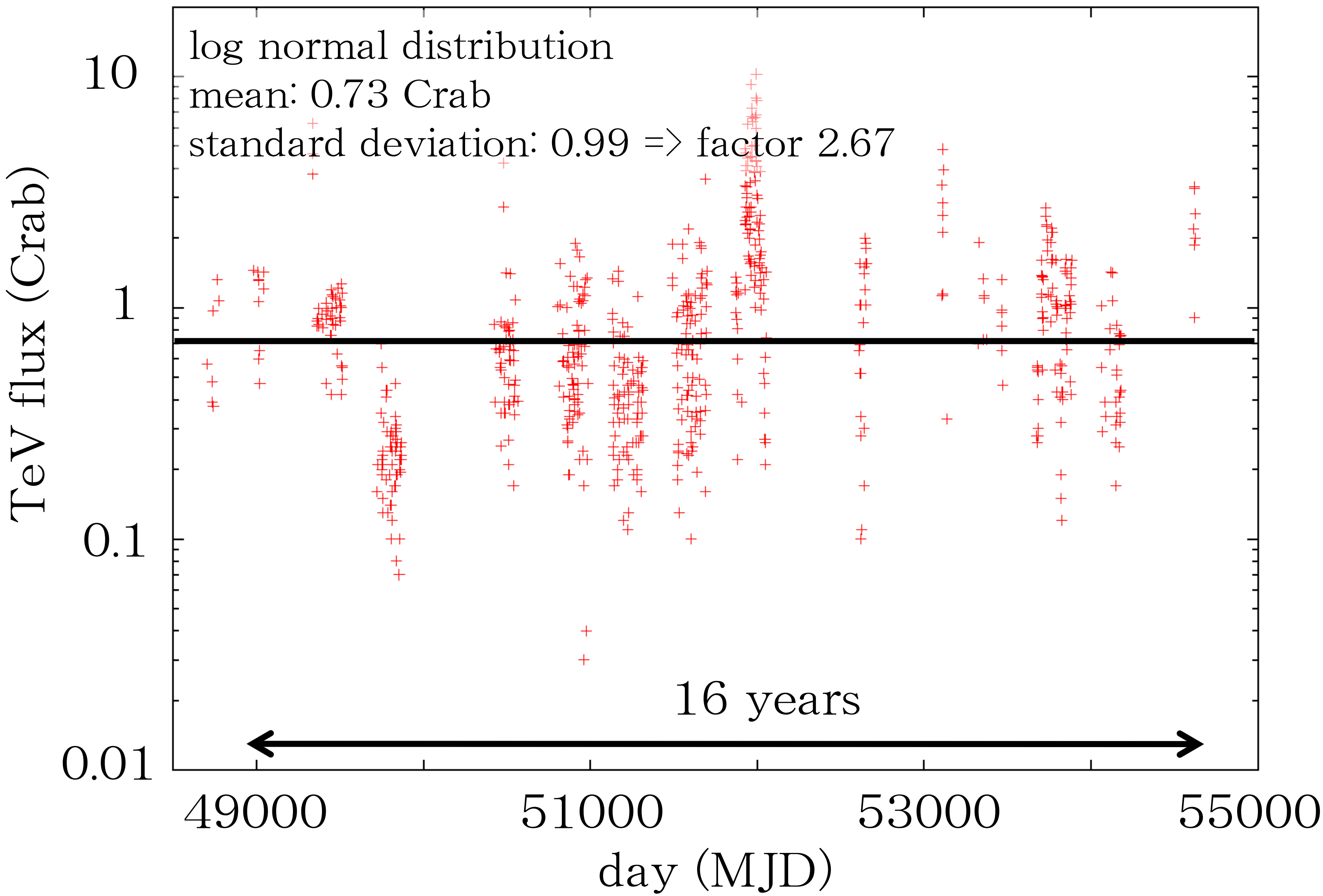
Let’s move on to TeV blazar.

Mkn421

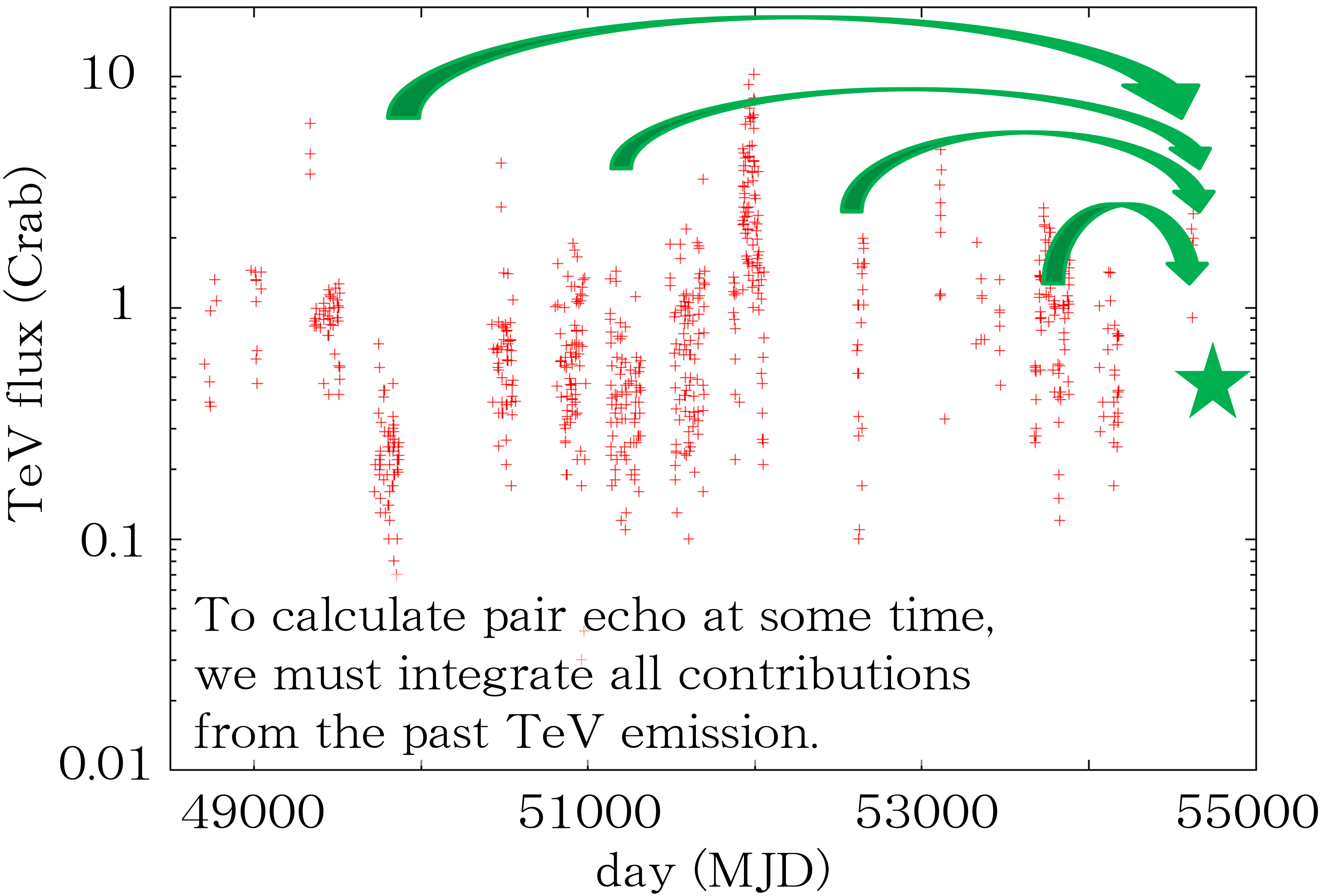
Nearest, hardest, best-observed TeV blazar



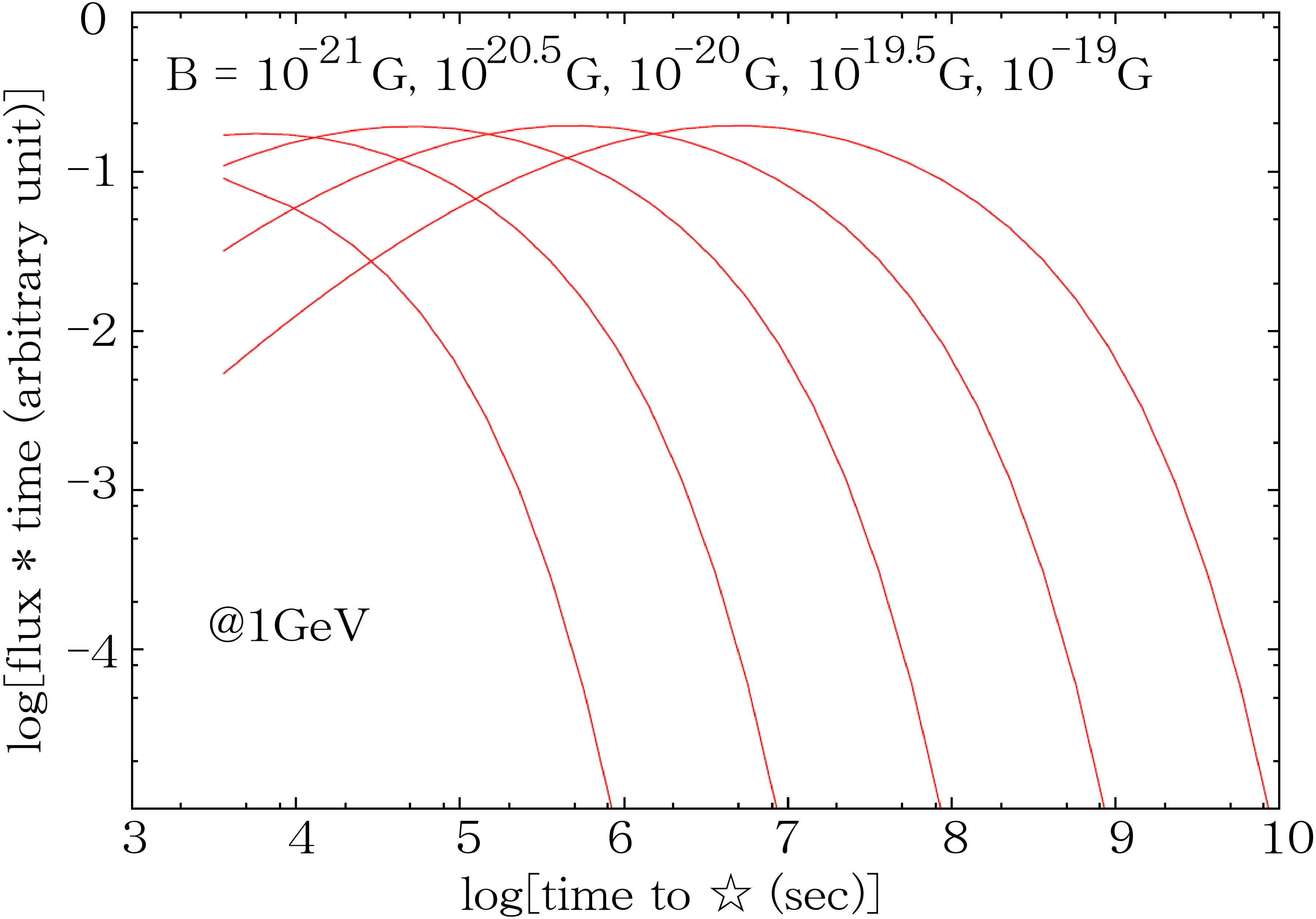
Mkn421 Nearest, hardest, best-observed TeV blazar



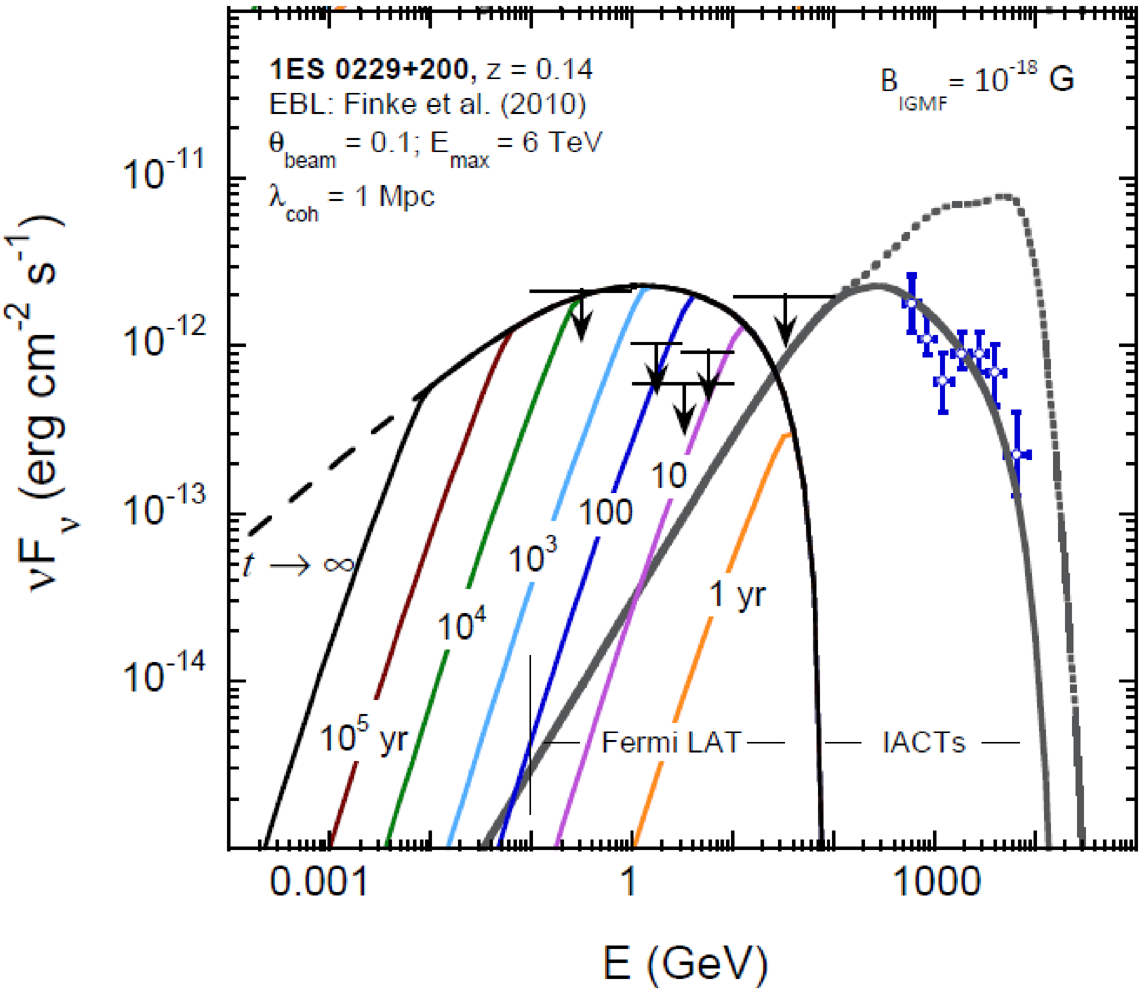
Mkn421 Nearest, hardest, best-observed TeV blazar



How distant past is important?



Dermer et al., 2010①

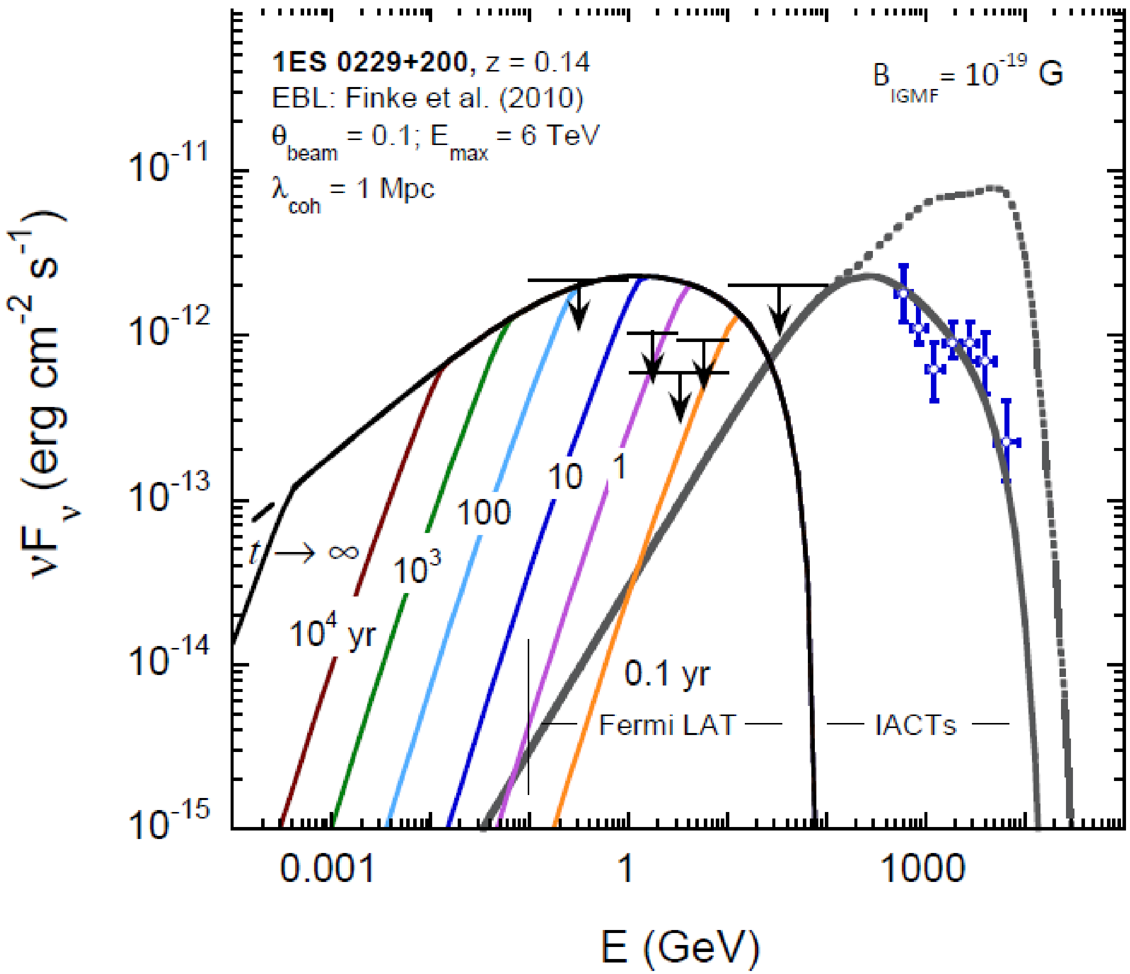


No observation by Fermi in 0.1–100GeV range.

If the blazar has emitted TeV gamma-rays for more than 100 years at the level of 2009, $B = 10^{-18}$ G is constrained.

Because 1ES 0229+200 has been observed for several days in 2005, 2006 and 2009, this is a strong assumption.

Dermer et al., 2010②



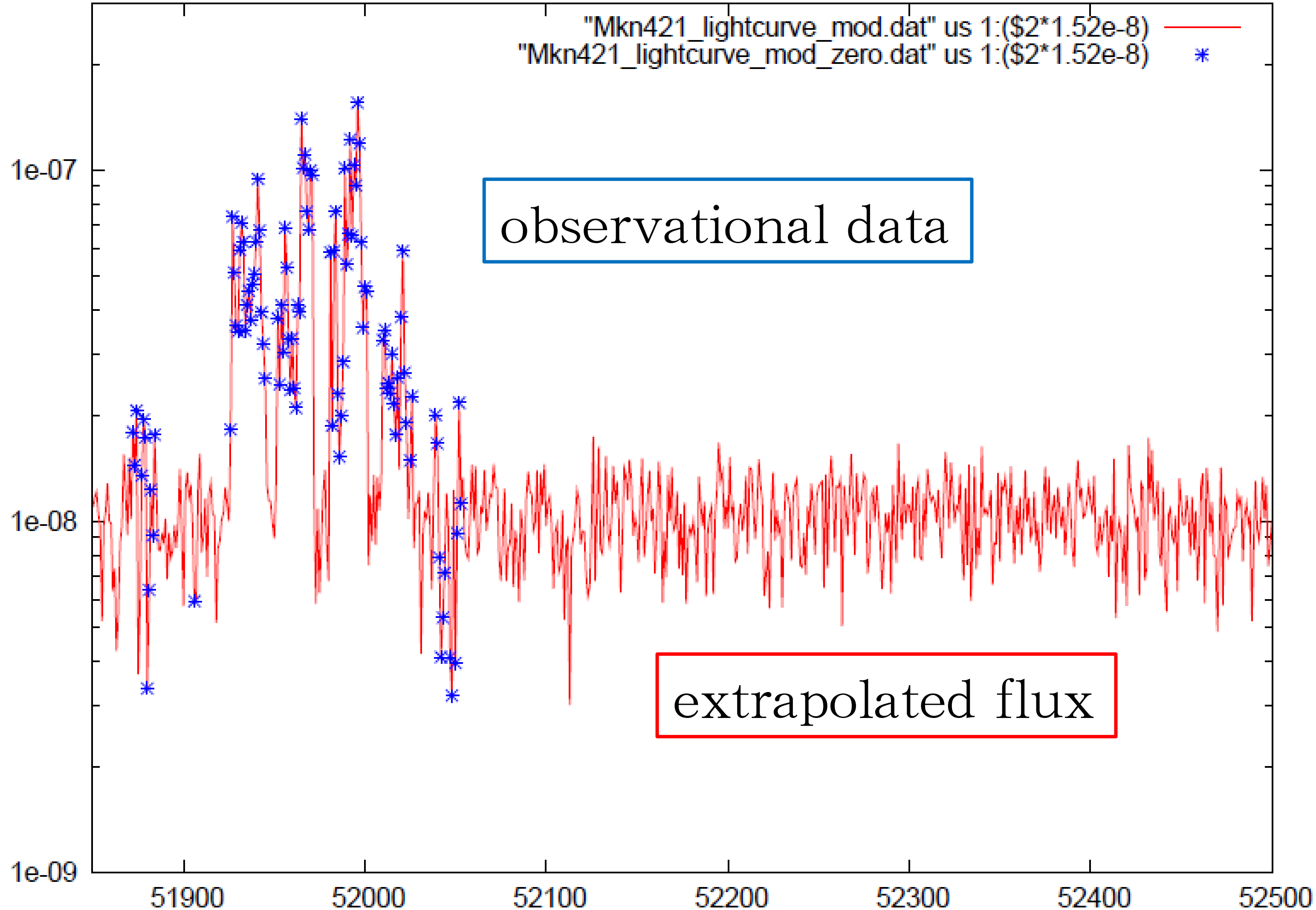
For $B = 10^{-18}$G, 1-year emission is sufficient to constrain. This would be a more reasonable assumption.

Relatively robust, but still based on an assumption on the past TeV emission.

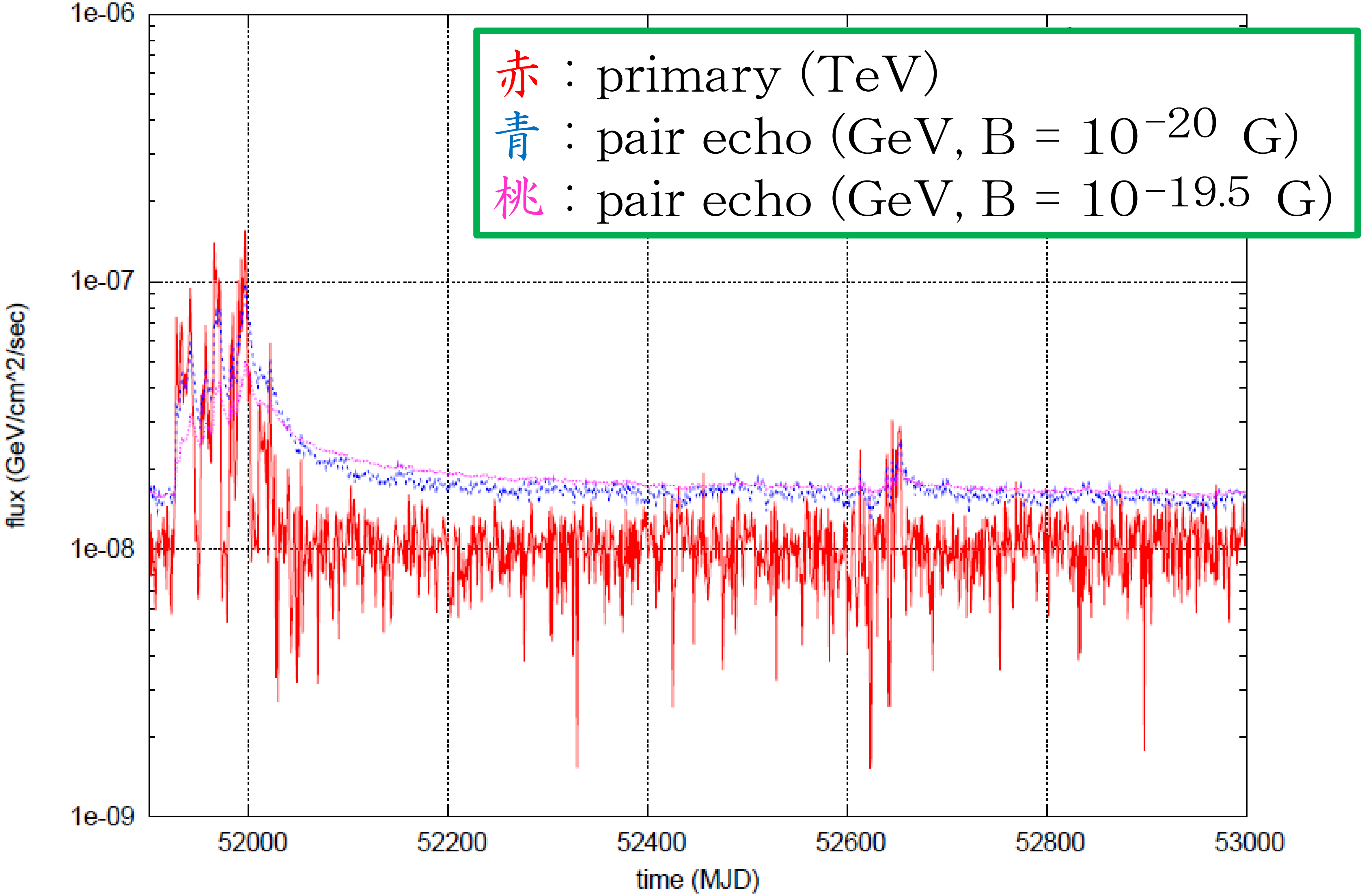
4 years => $B_{IGMF} \gtrsim 3 \times 10^{-19}$ G

mock Mkn421 data①

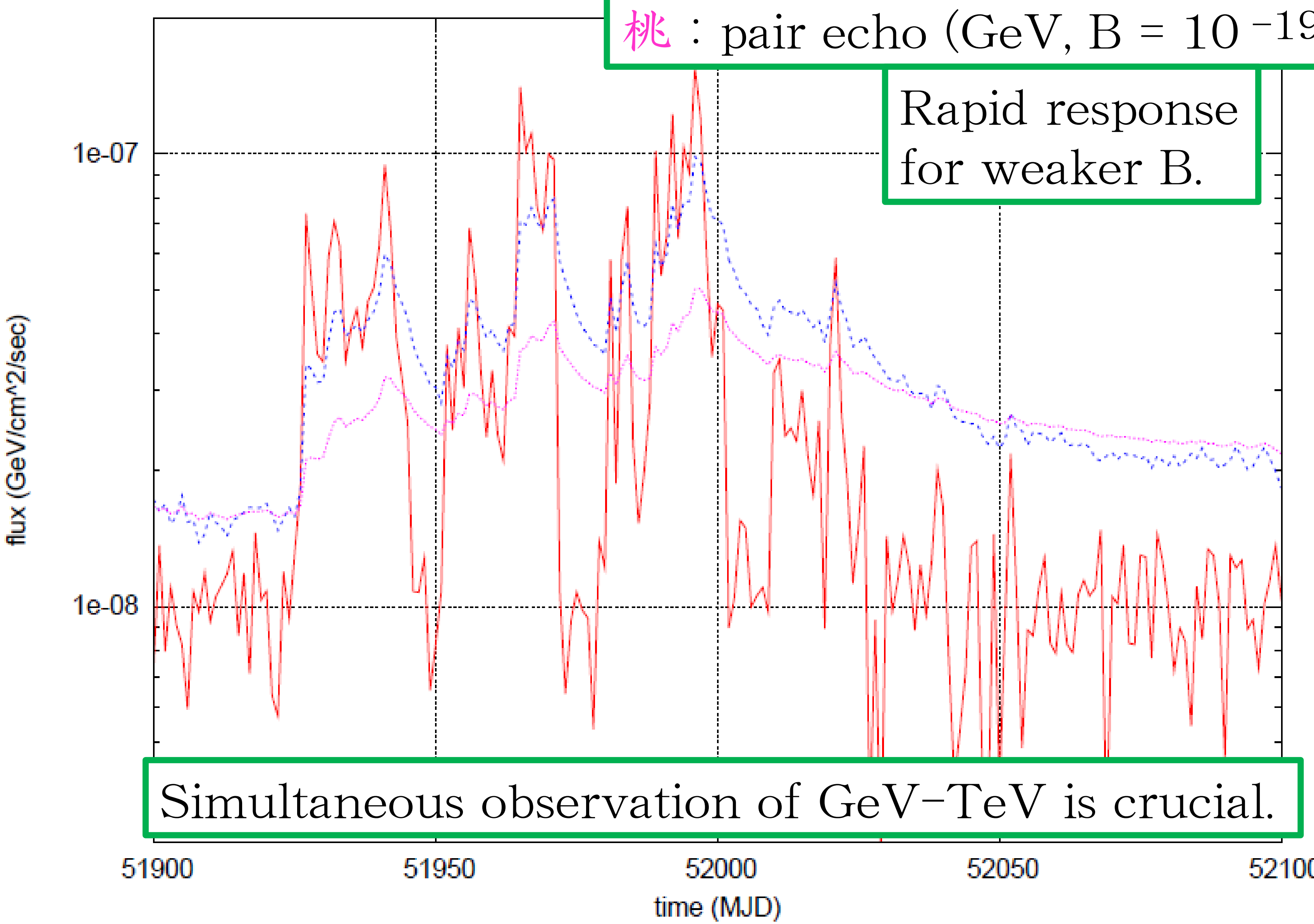
What is the lightcurve of pair echo from blazars?
Demonstration with a mock TeV lightcurve of Mkn421



mock Mkn421 data②

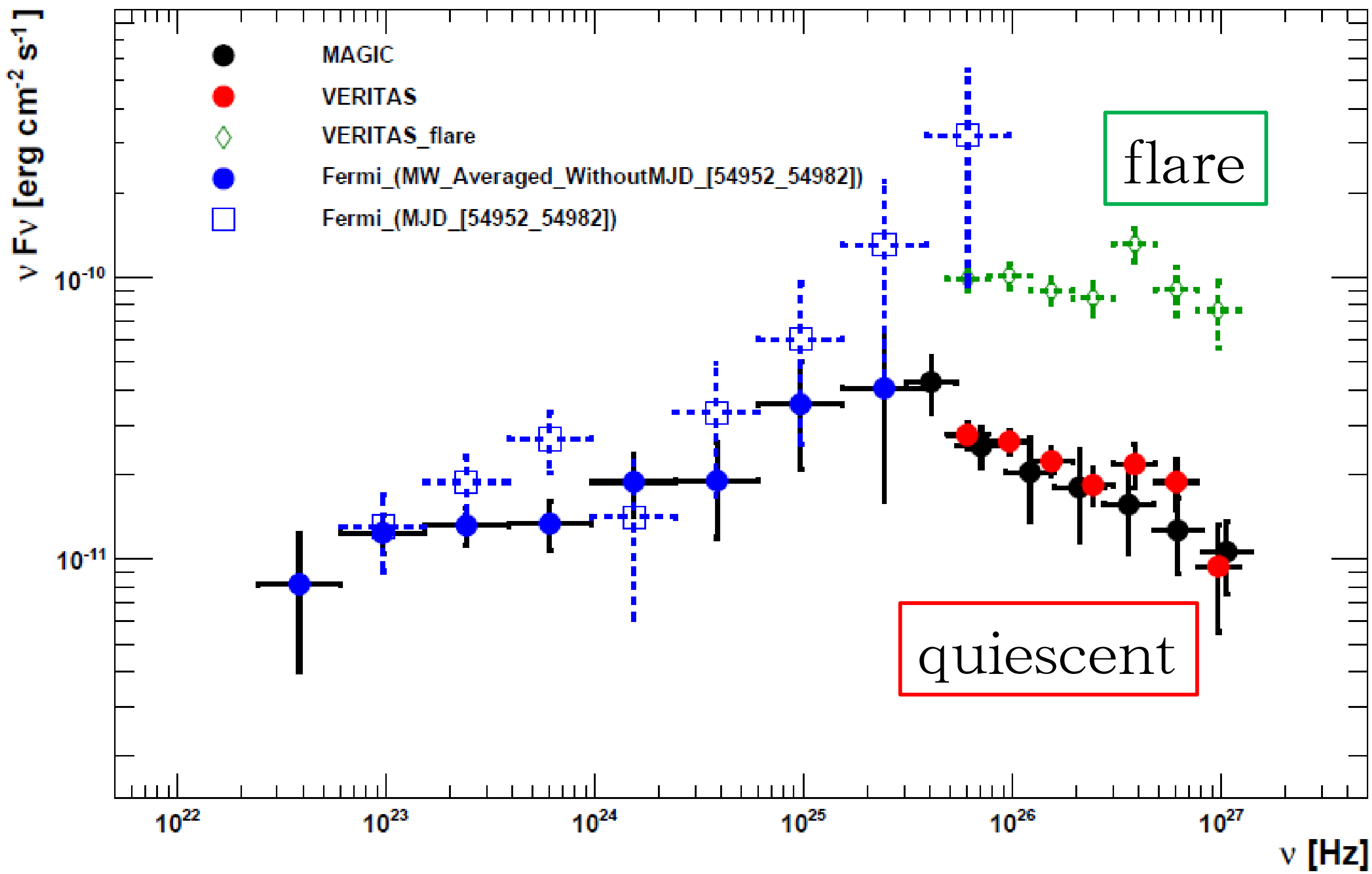


mock Mkn421 data



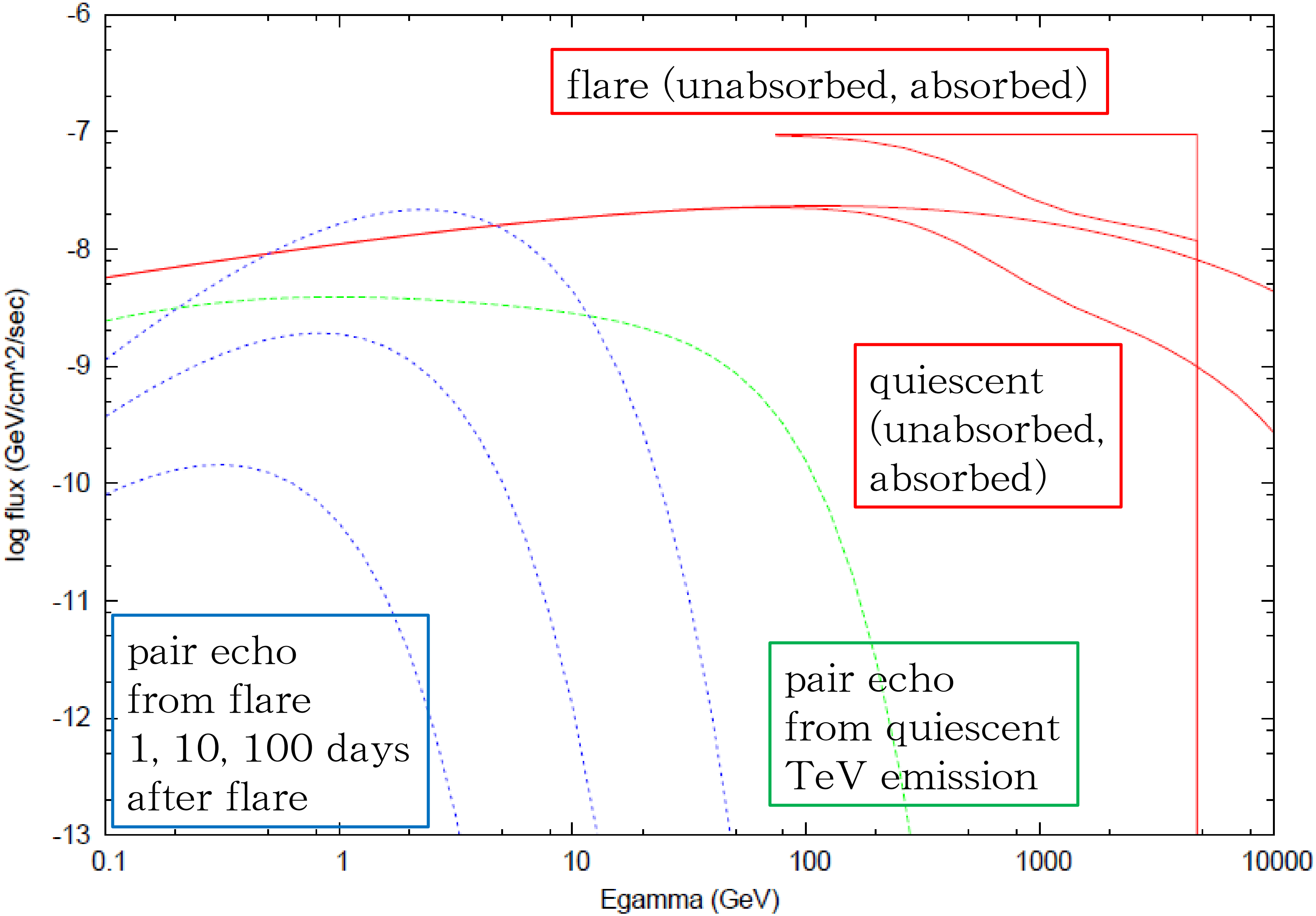
Mkn501 flare①

Abdo et al., 2010
multiwavelength observation for 480 days
flare for (more than) 3 days



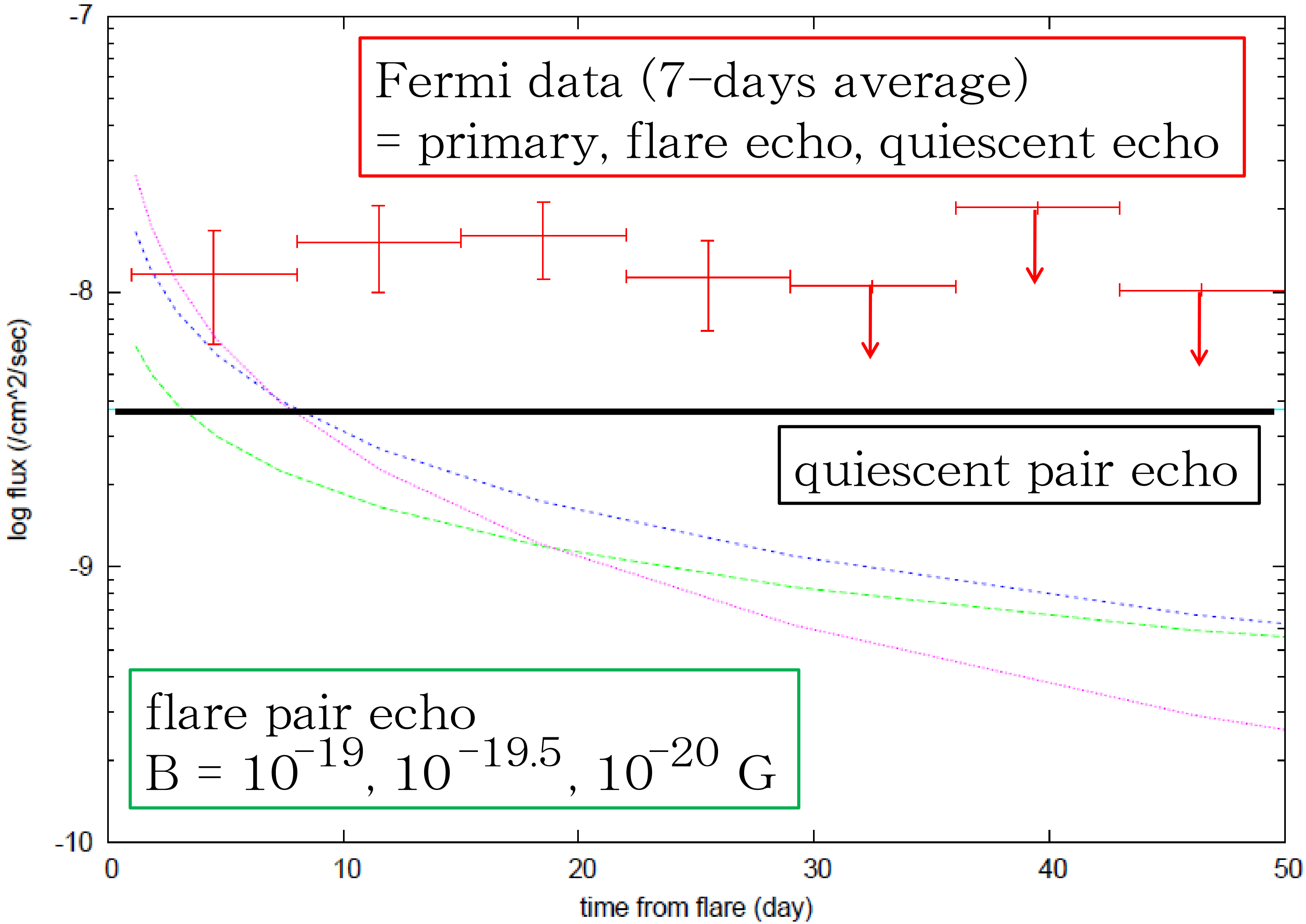
Mkn501 flare②

KT+, in preparation



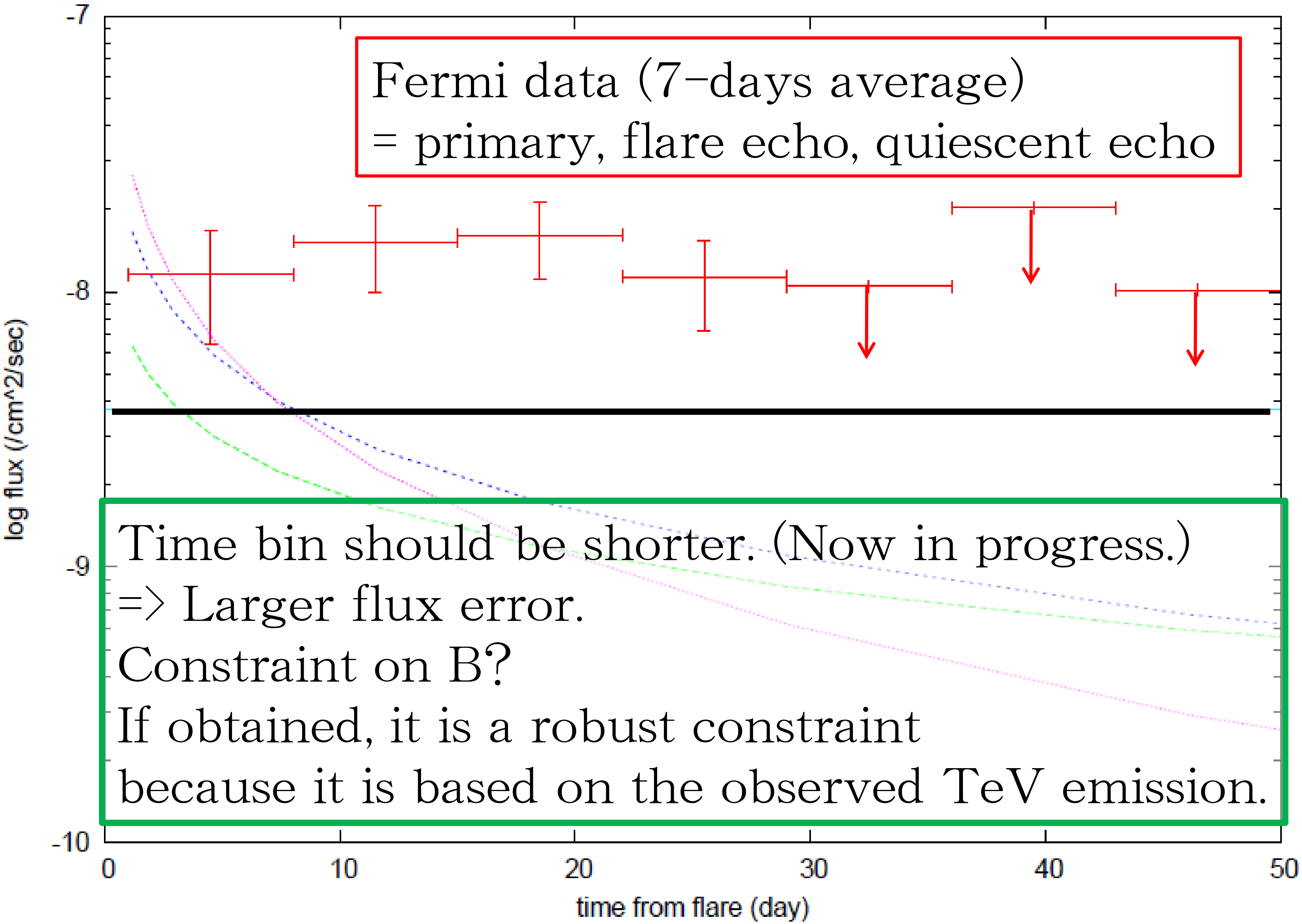
Mkn501 flare③

lightcurve of 1−10GeV



Mkn501 flare④

lightcurve of 1-10GeV



Fermi data (7-days average)
= primary, flare echo, quiescent echo

Time bin should be shorter. (Now in progress.)
=> Larger flux error.
Constraint on B?
If obtained, it is a robust constraint
because it is based on the observed TeV emission.

summary

- Pair echo (halo) can probe the weakest B.
- 3 ways to observe pair echo.
  - spectral modification
  - extended halo
  - time delay
- Time delay has an advantage that it does not need to assume TeV activity in unobserved past.
- Robust constraints could be obtained by simultaneous observations of blazars in GeV-TeV range.

comment

magnetogenesis from primordial fluctuations

- KT+, 05, 06, 07, 08
- Pitrou+, 10

Are we consistent?

KT+, 06