TeV Gamma-Ray Afterglow in Shallow Decay Phases of GRBs

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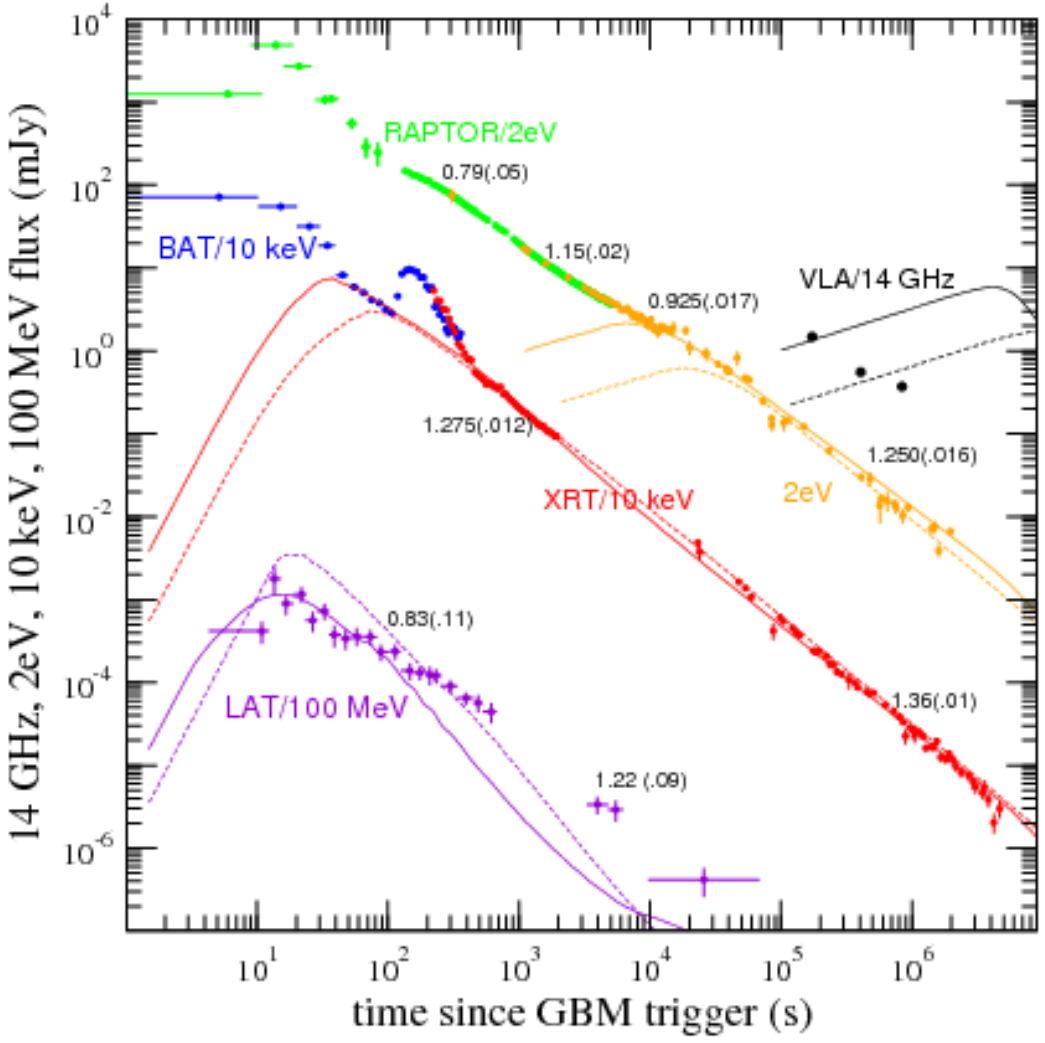
Afterglow of Gamma-Ray Bursts

Afterglow



- Decaying multi-wavelength emission after GRBs
- Relativistic shock propagating in the external medium
- ISM (constant density) or stellar wind?
- Synchrotron emission from Fermi-accelerated electrons
- Jet break in later phase
- Reverse shock component also?

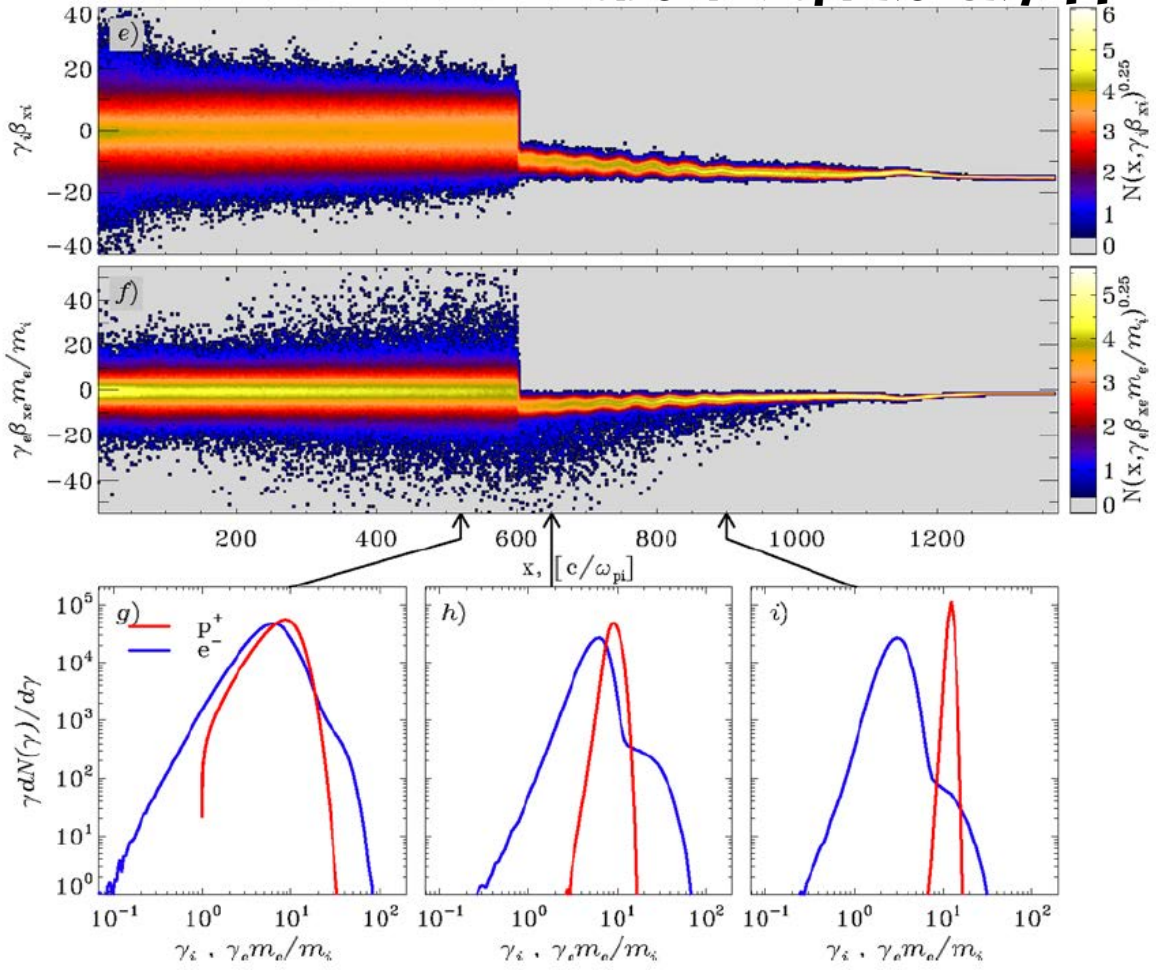
TeV afterglows:

GRB 180720B (HESS), 190114C(MAGIC), 190829A (HESS, z=0.42), 201216C (MAGIC, z=1.1), 221009A (LHAASO, z=0.15)

Electron heating/acceleration

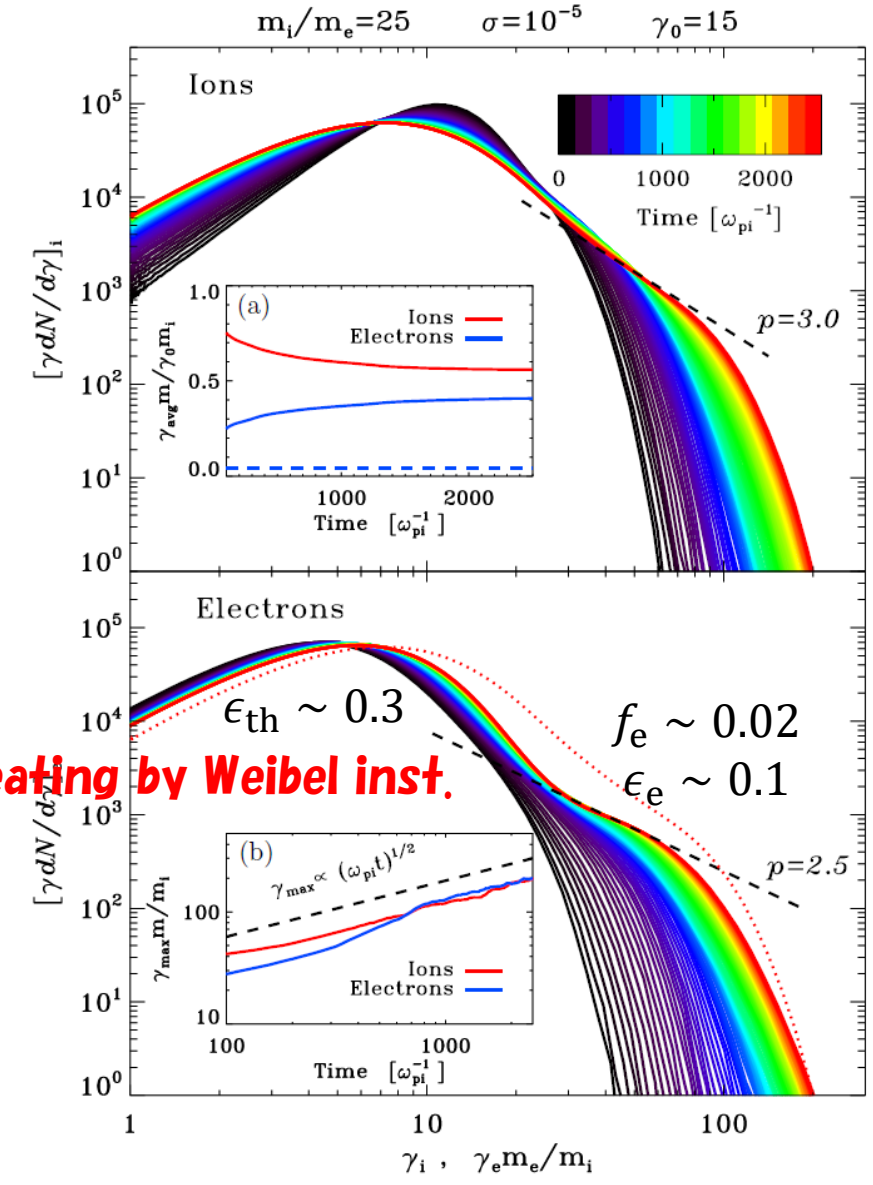
Sironi+ 13

Sironi & Spitkovsky 11



$\sigma = 0.1$

Pre-heating in the upstream



Heating by Weibel inst.

$\epsilon_{\rm th} \sim 0.3$

$f_{\rm e} \sim 0.02$

$\epsilon_{\rm e} \sim 0.1$

Acc. time

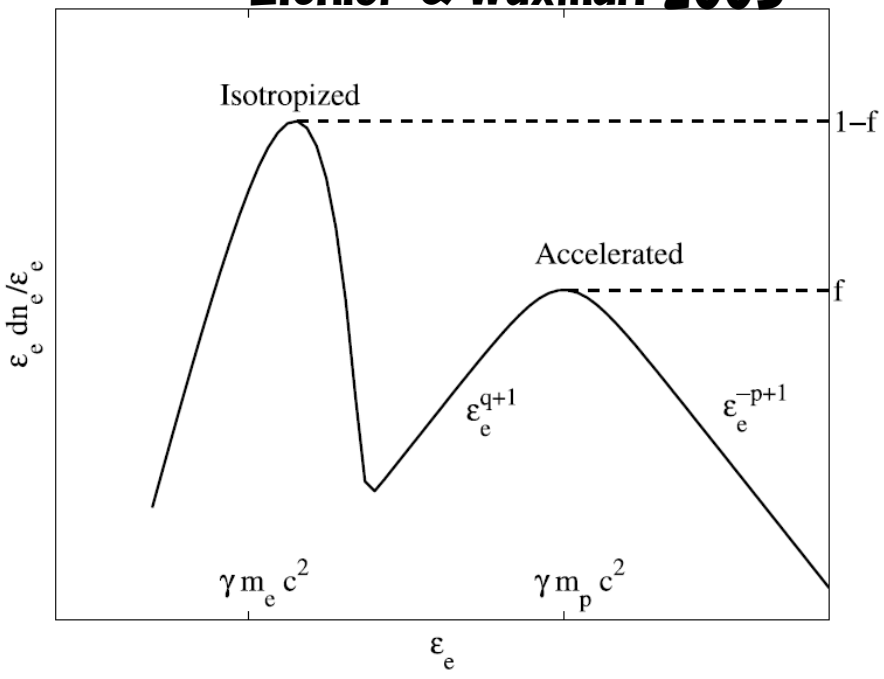
$$t_{acc} \simeq \eta \frac{r_{\rm L}}{c}$$

$$\eta = \frac{r_{\rm L}}{\lambda_{\rm min}}$$

$$\gamma_{\rm max} \propto t^{1/2}$$

Electron Acc. in the conventional model

Eichler & Waxman 2005

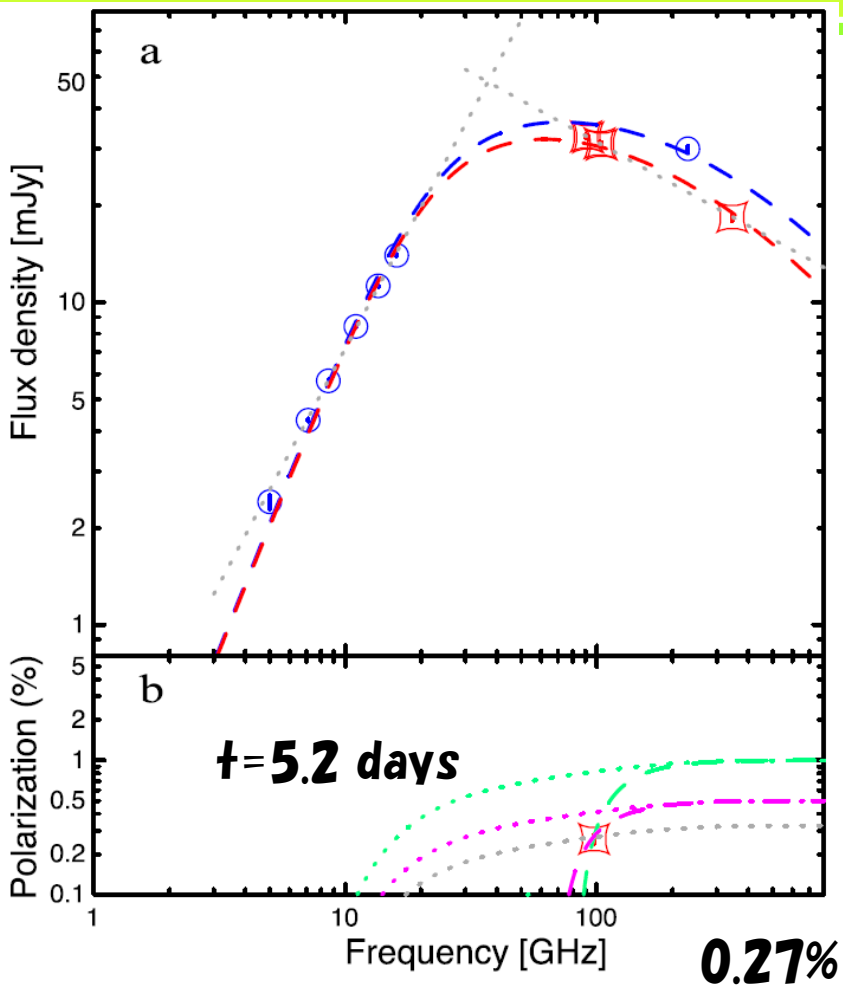


Thermal & Non-thermal

$$\gamma_{\rm m} \simeq \frac{\epsilon_{\rm e}}{f_{\rm e}} \frac{p-2}{p-1} \Gamma \frac{m_{\rm p}}{m_{\rm e}},$$

$f_{\rm e} \sim 1$?

Urata+ 19, GRB 171205A



0.27% ± 0.04%

Depolarization by thermal electrons?

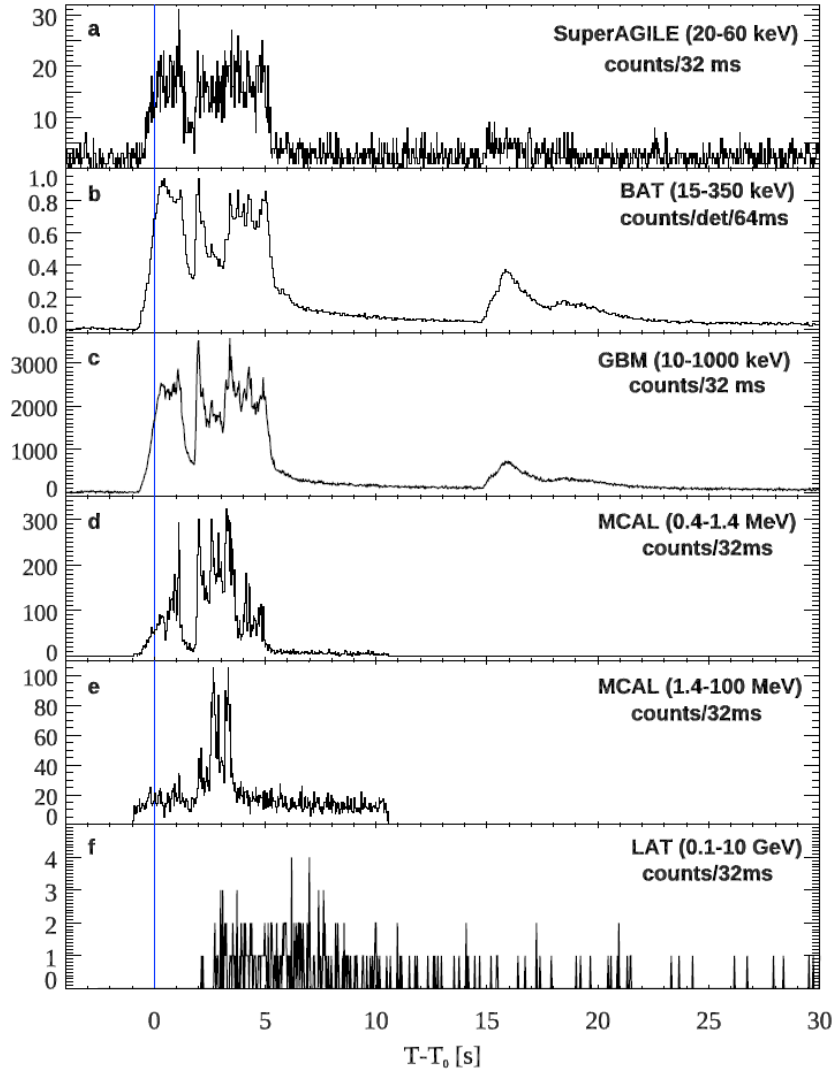
⇒ $f_{\rm e} \sim 0.1$

GRB 190114C

$z = 0.42$ **Nearby**
Prompt Rad. $E_{\rm iso} \simeq 2.5 \times 10^{53}$erg

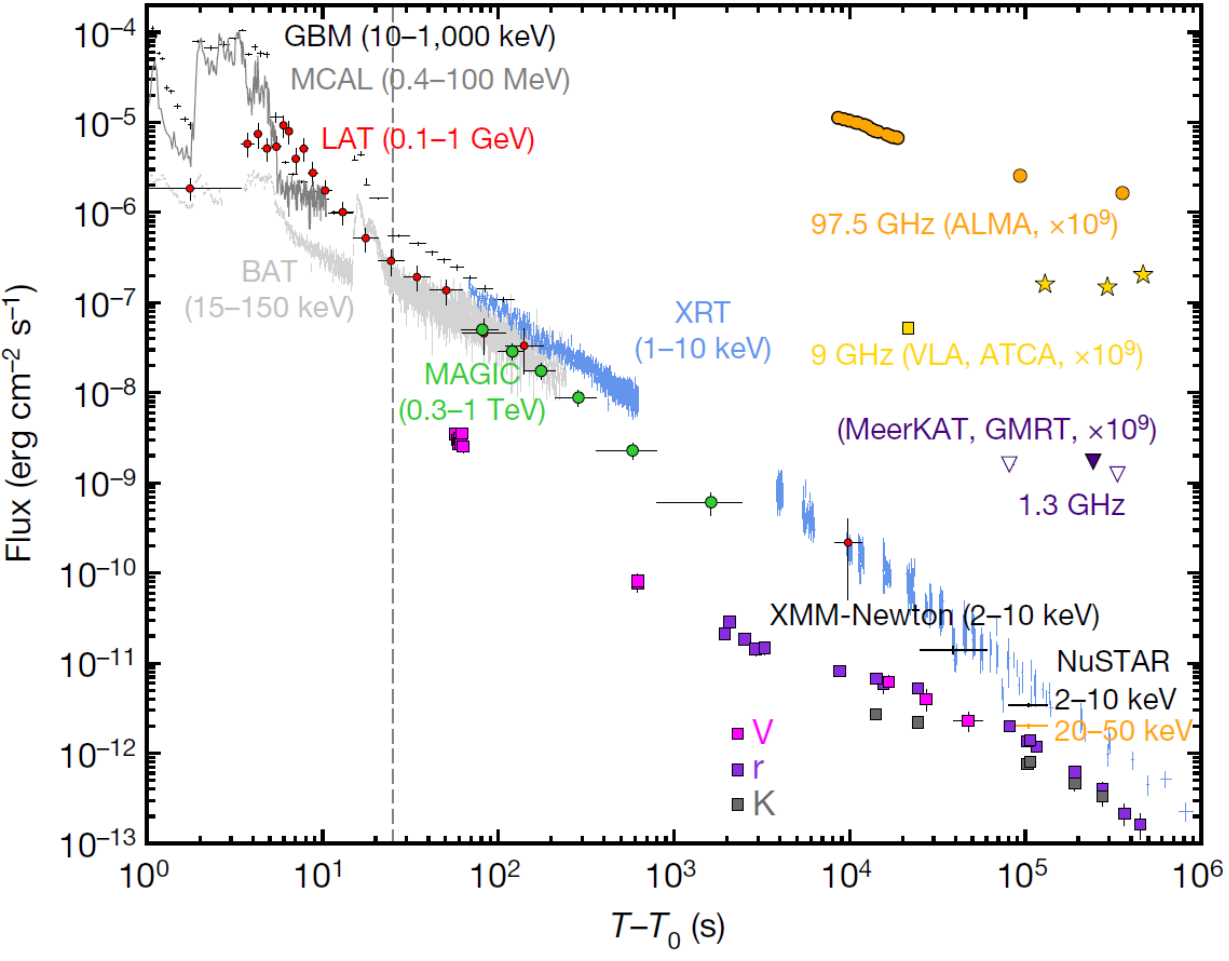
'First' Detection by Cherenkov Telescope

MAGIC: Diameter 17m x2, Rotation with ~7deg/s
Low energy threshold >50GeV
Start obs. at t=60s, Detected ~1000 photons

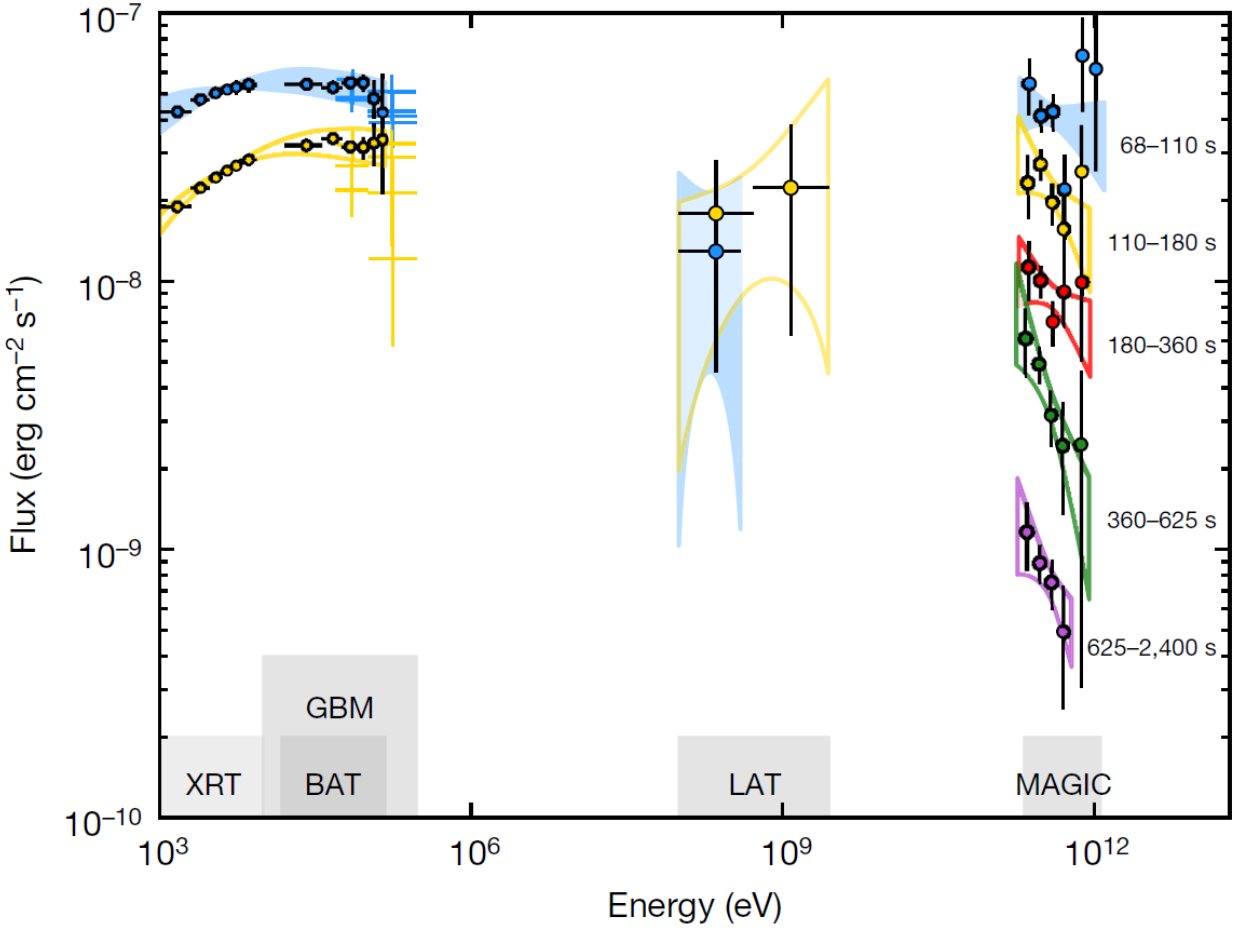


Lightcurves

Multiwavelenghth Lightcurves & Spectra

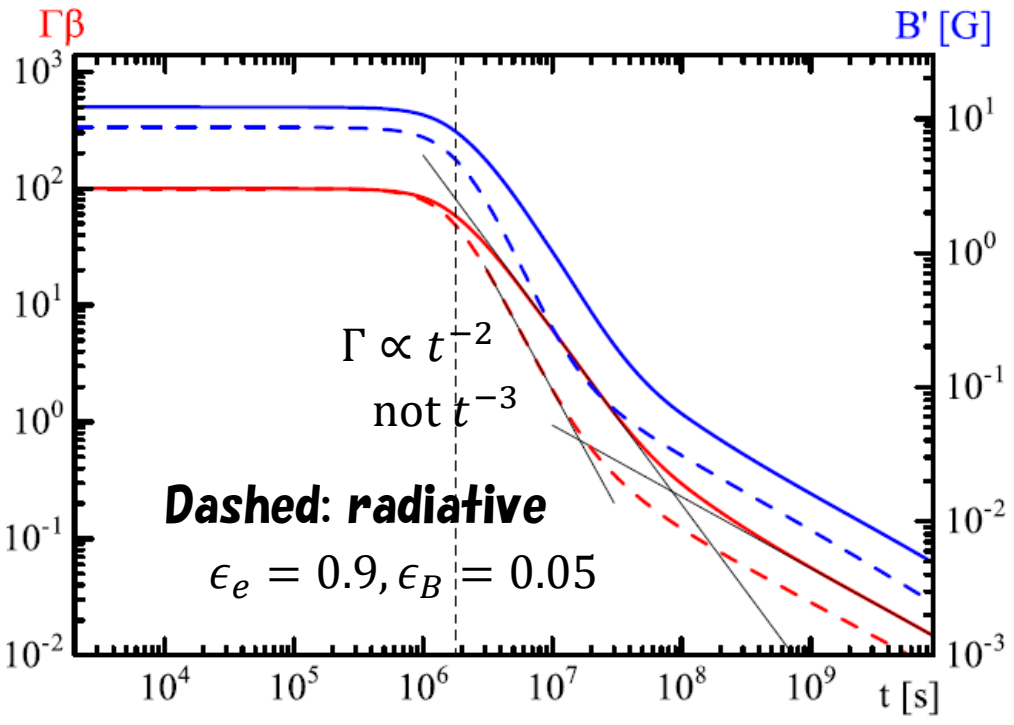


Gamma-ray Afterglow



Corrected for EBL abs.

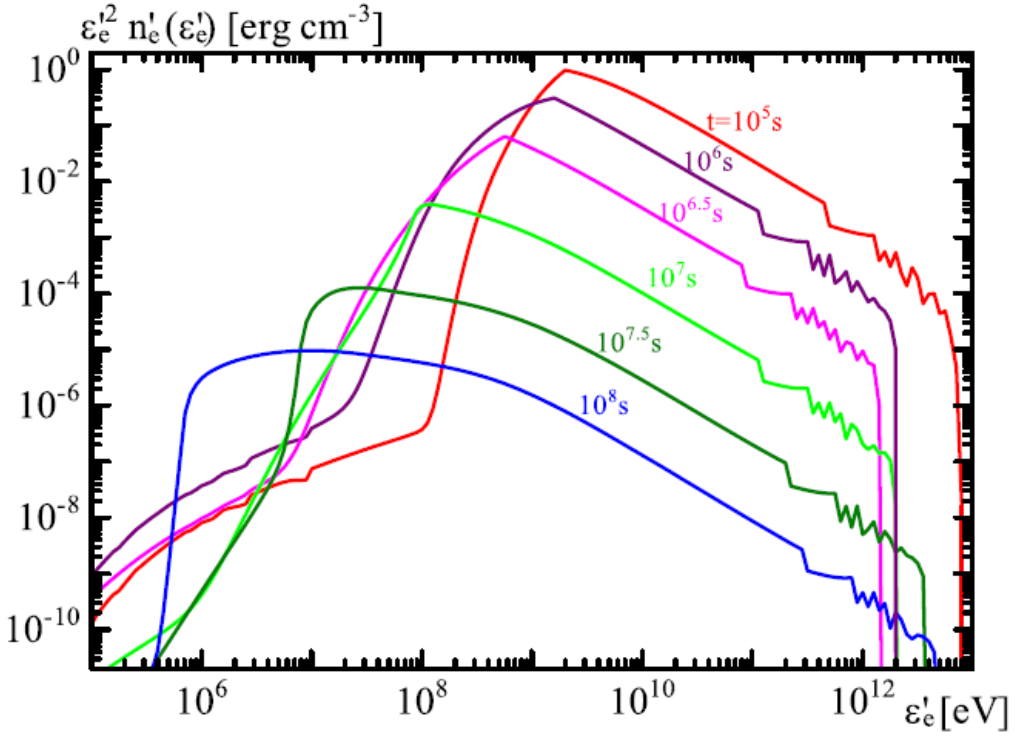
1D time-dependent calculation

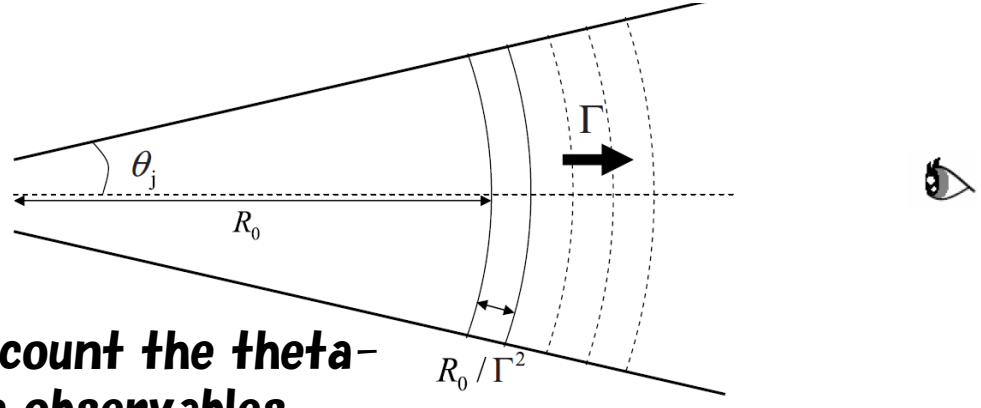


$E_0 = 10^{52}\mathrm{erg}, \Gamma_0 = 100, n_{\mathrm{ISM}} = 1\mathrm{cm}^{-3}, p = 2.2,$
$\epsilon_e = \epsilon_B = 0.1$

Fukushima, KA+ 2017

Electron energy distribution



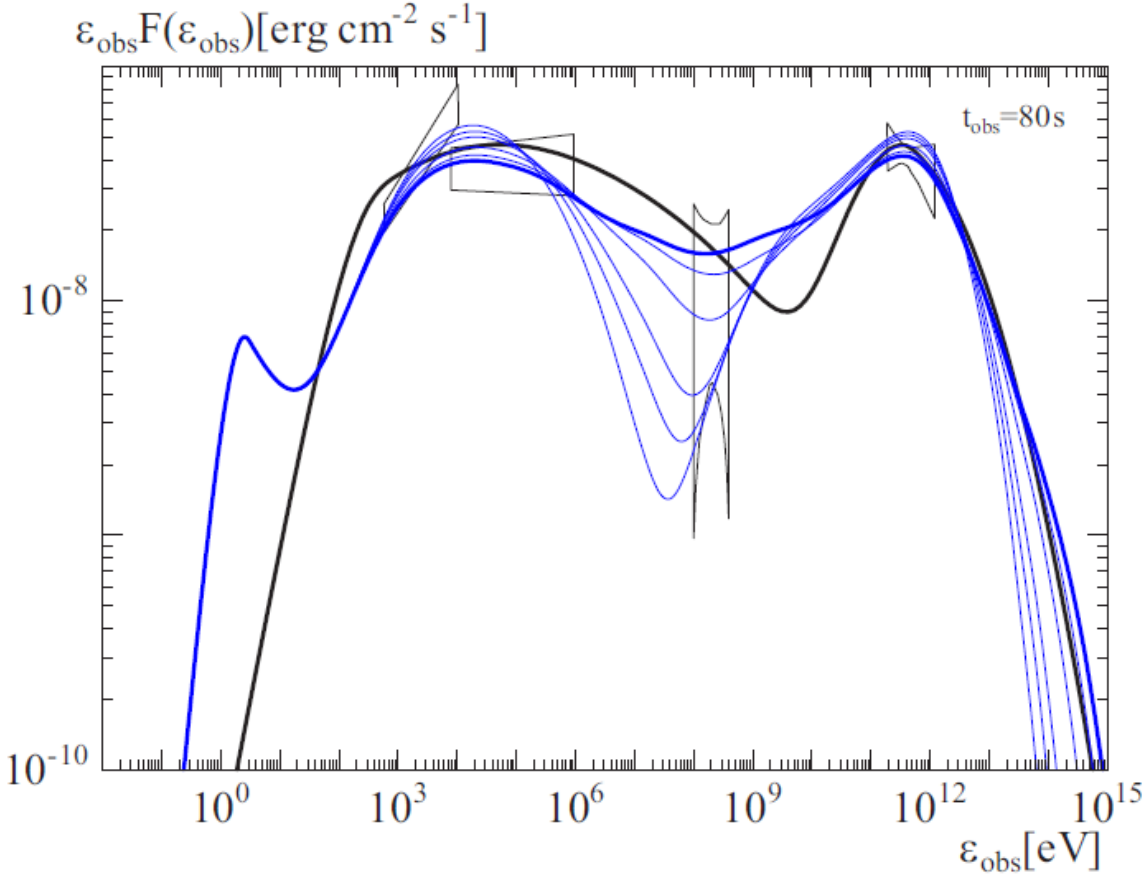


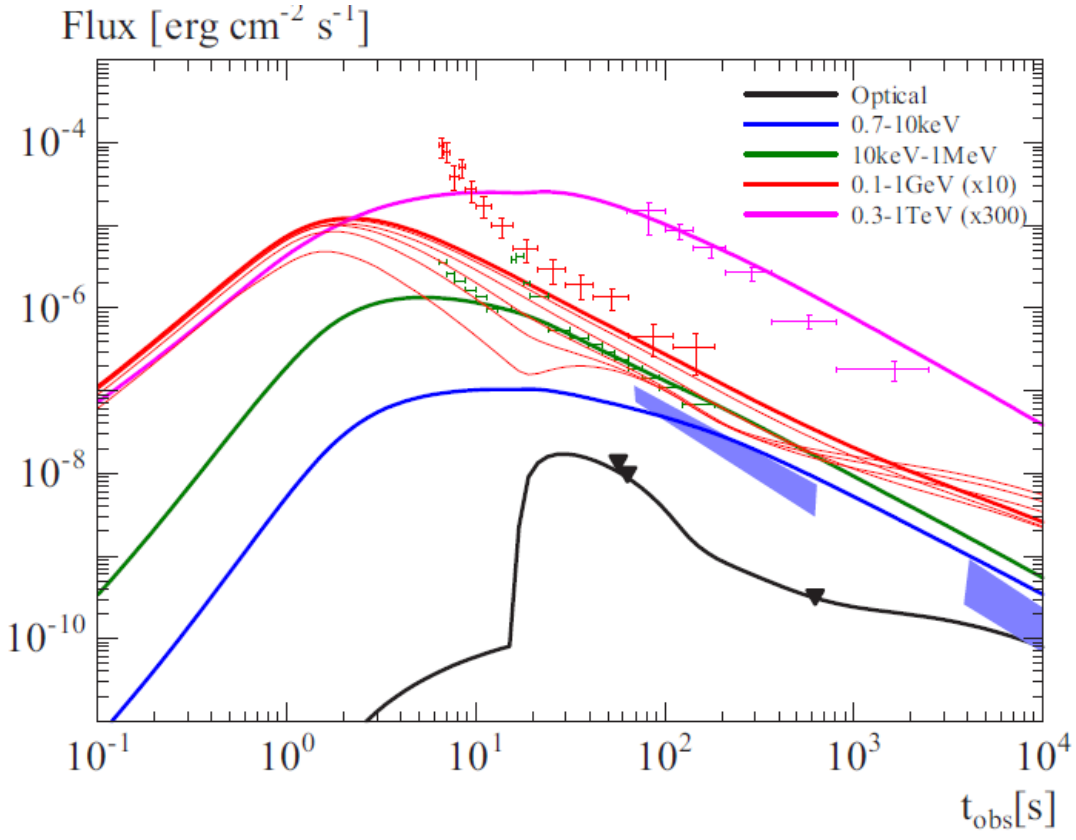
Taking into account the theta-dependence on observables.

ISM Model

Model	E_0 [erg]	Γ_0	n_0 [cm^{-3}]	A	p	ϵ_e	ϵ_B	f_e
ISM (method I)	10^{54}	600	1.0	—	2.3	0.06	9.0×10^{-4}	0.3
Wind (method I)	10^{54}	300	—	0.1	2.35	0.08	1.2×10^{-3}	0.3
ISM (method II)	4×10^{53}	—	0.3	—	2.3	0.1	1.0×10^{-3}	1.0

Fermi-LAT photon index: ~-2



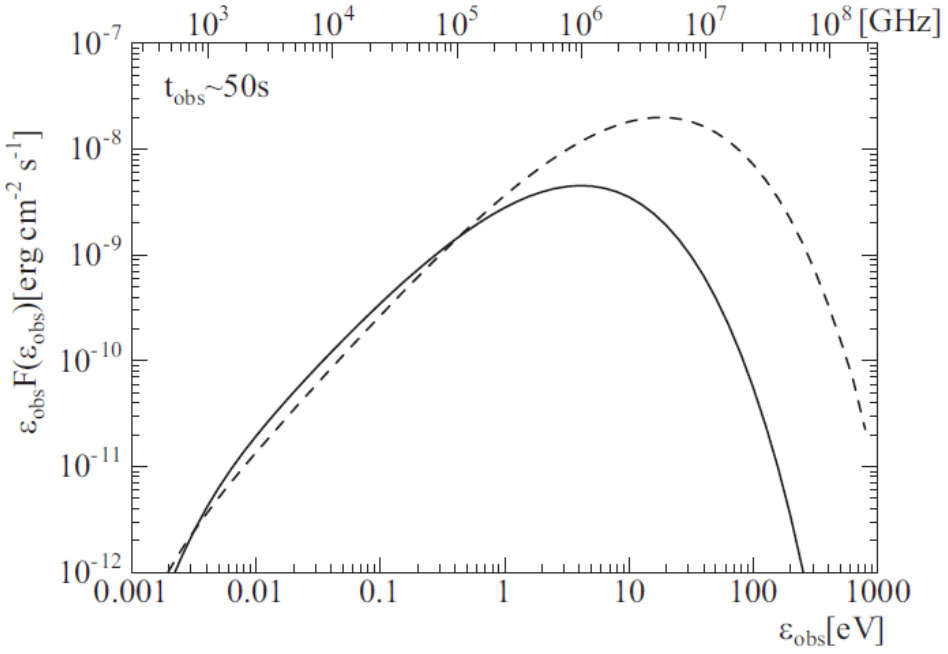


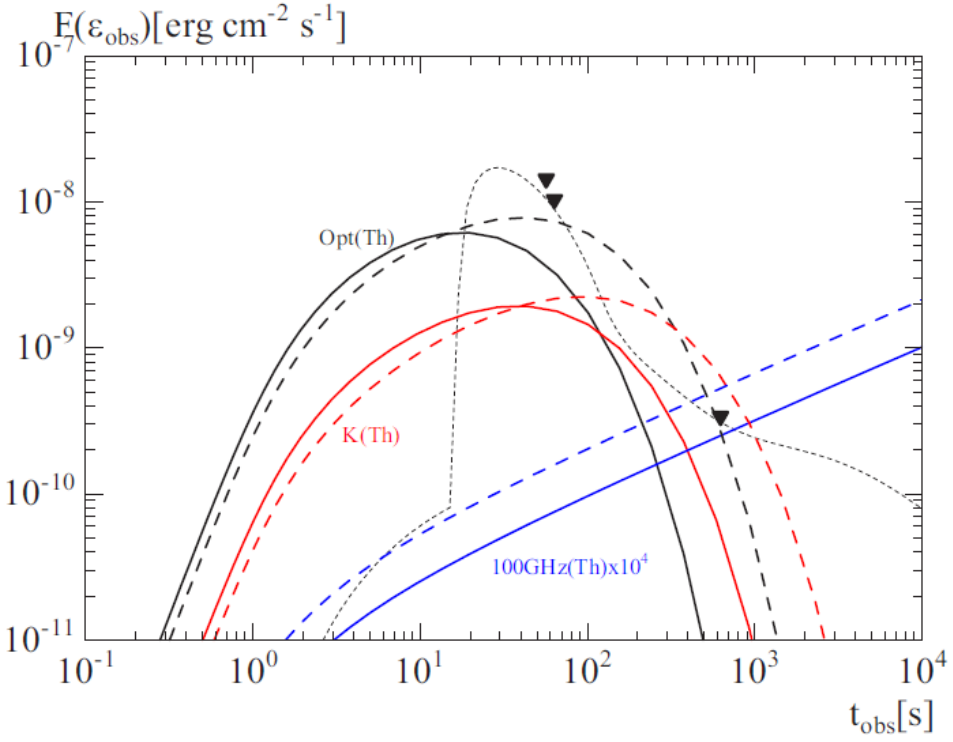
$$t_{\mathrm{acc}} \sim \eta \frac{r_L}{c}$$

$\eta = 1, 10, 100, 1000, 3000, 10000$

$$\gamma_{\max} \approx \left(\frac{\pi}{2\epsilon_B n m_p}\right)^{1/4} \left(\frac{3e}{2\eta\Gamma c\sigma_T}\right)^{1/2}$$

Optical emission via thermal synchrotron

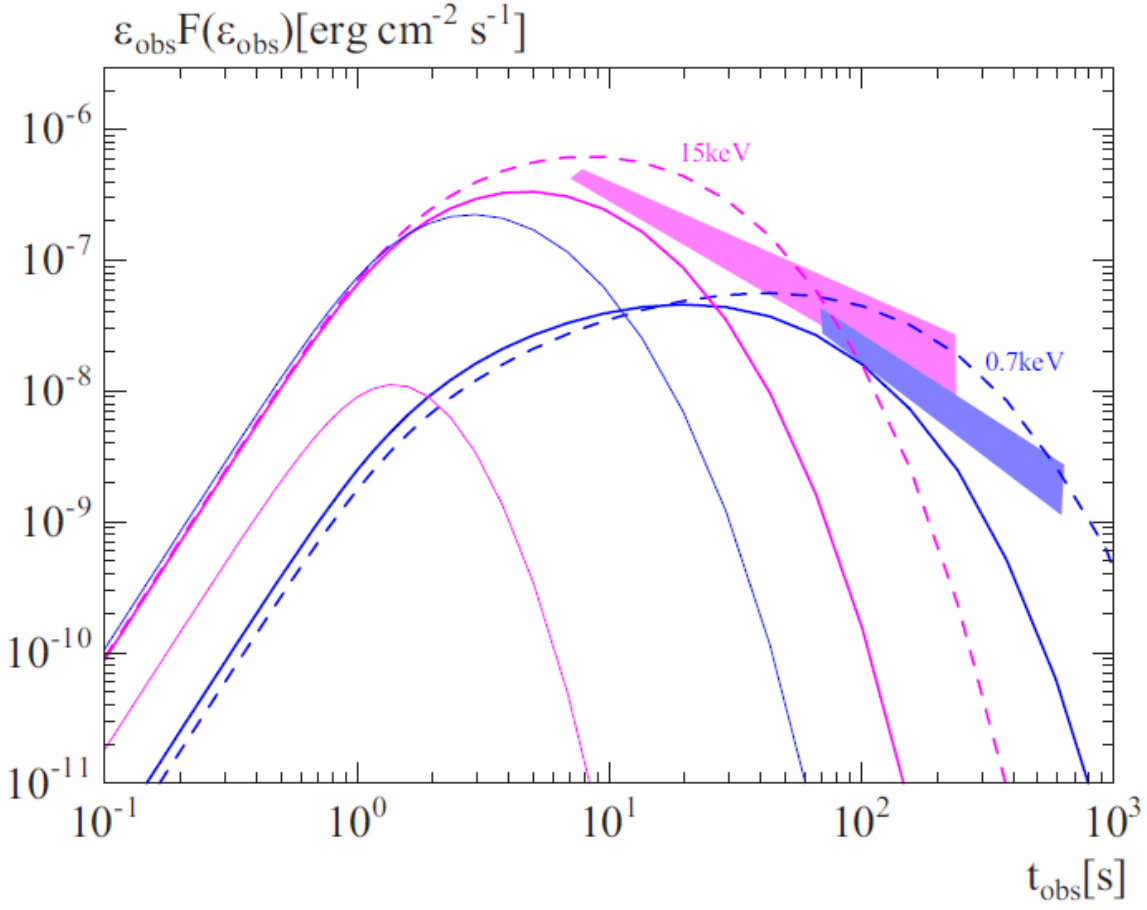




$f_e = 0.01$, and adopt $\epsilon_{th} = 0$ (solid) and 6×10^{-4} (dashed)

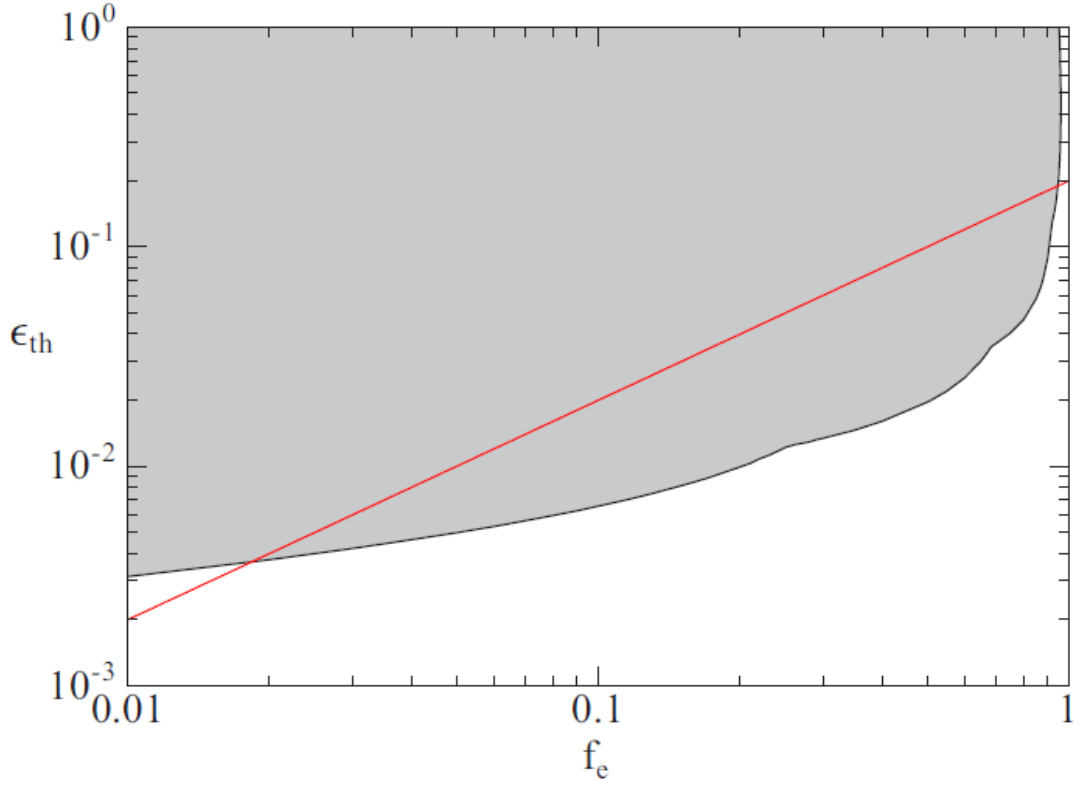
Optical emission has been considered to originate from reverse shock,
But, thermal synchrotron can explain also.
Heating efficiency lower than PIC sim. suggested

X-ray



Solid $f_e = 0.3$ & $\epsilon_{th} = 0.01$

Dashed $f_e = 0.3$ & $\epsilon_{th} = 0.02$

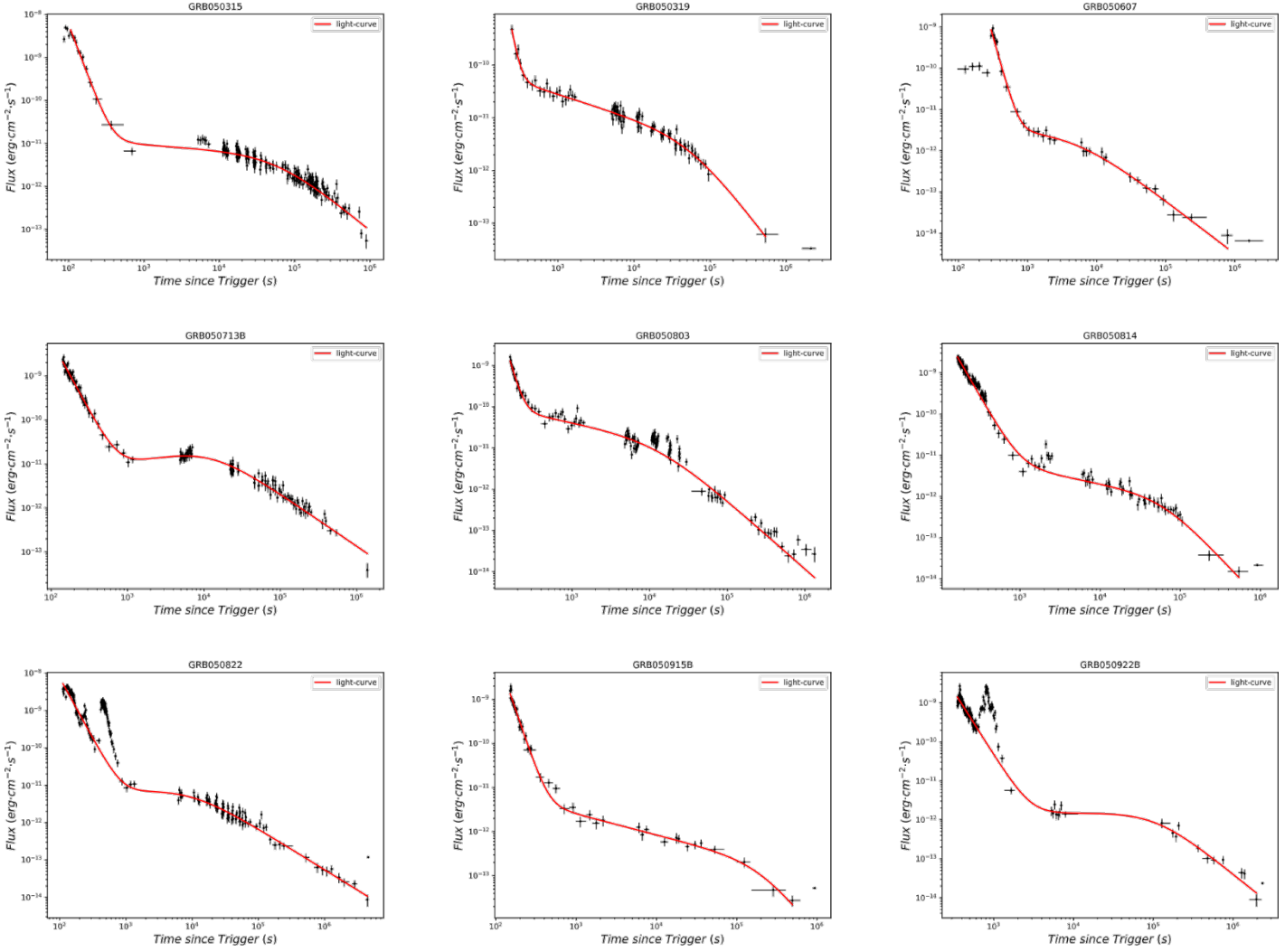


PIC simulations suggest $f_e = 0.01 - 0.1$
$\epsilon_{th} \sim 0.3$

Inconsistent!

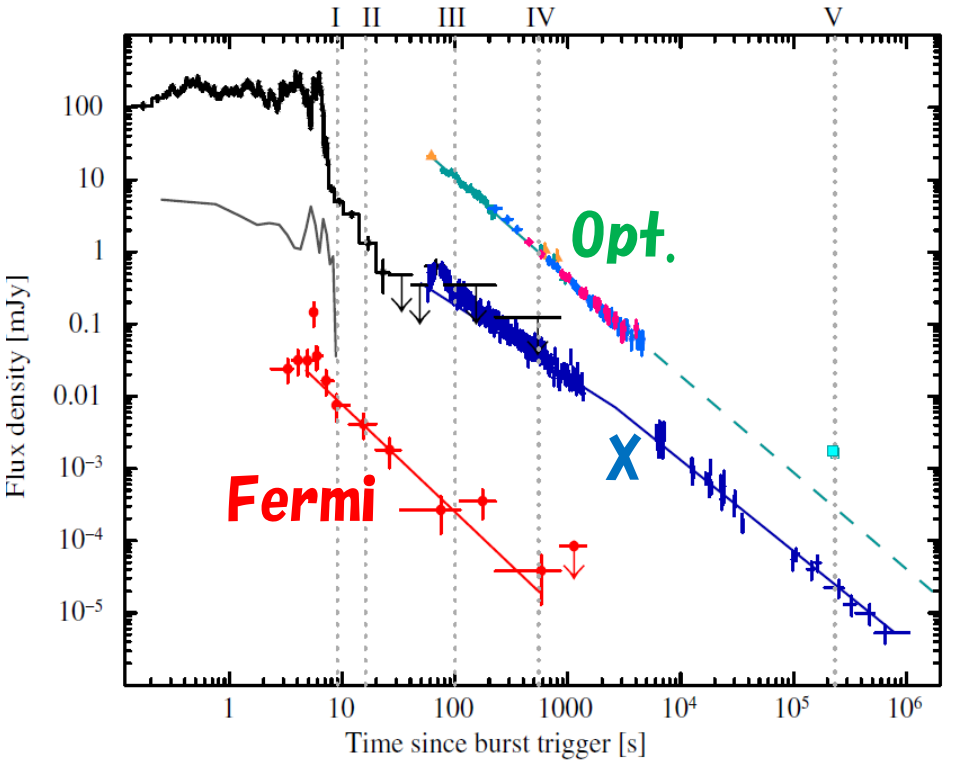
Shallow Decay Phase

X-ray LCs



X.-K. Ding+ 22

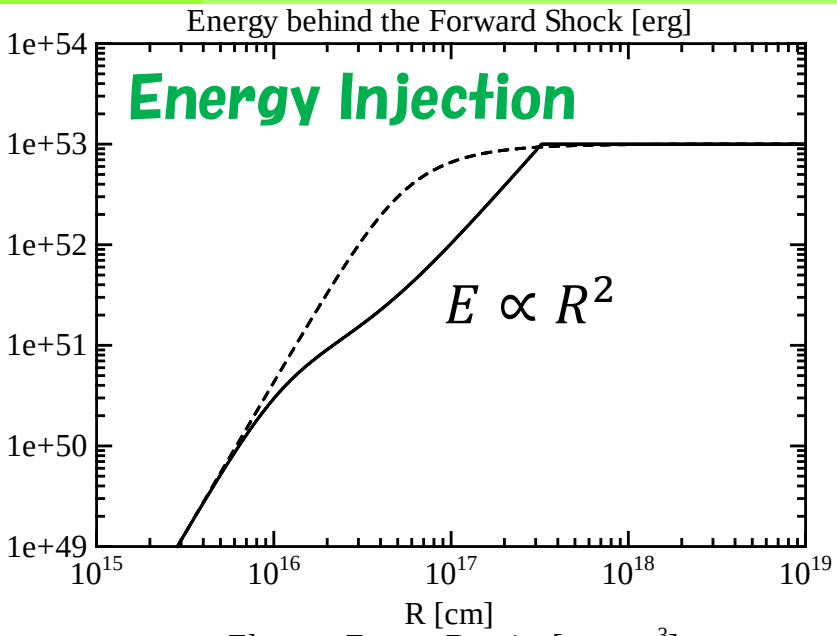
GRB 110731A (Ackerman+13)

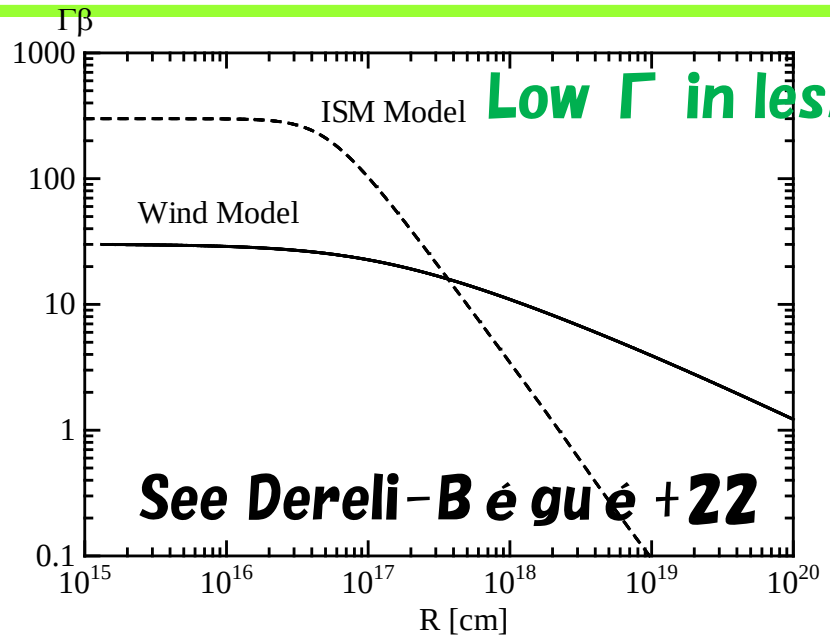


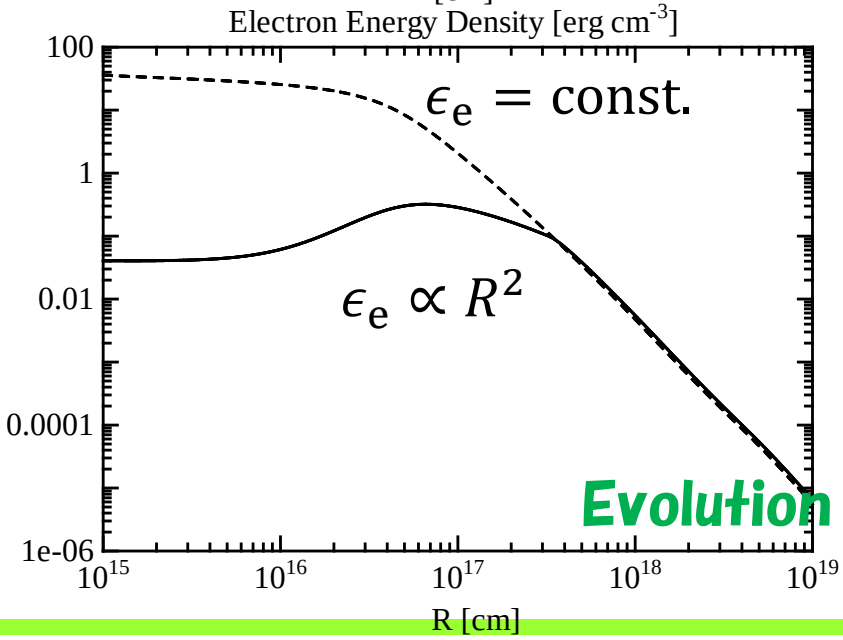
Fermi-LAT GRBs tend to show no shallow decay.

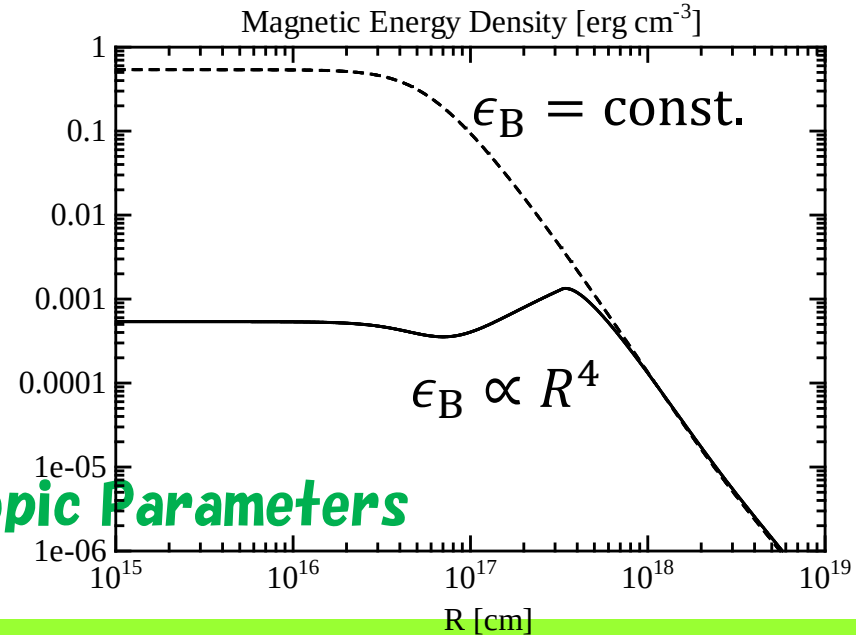
See Yamazaki+ 20

Model of Shallow Decay Phase





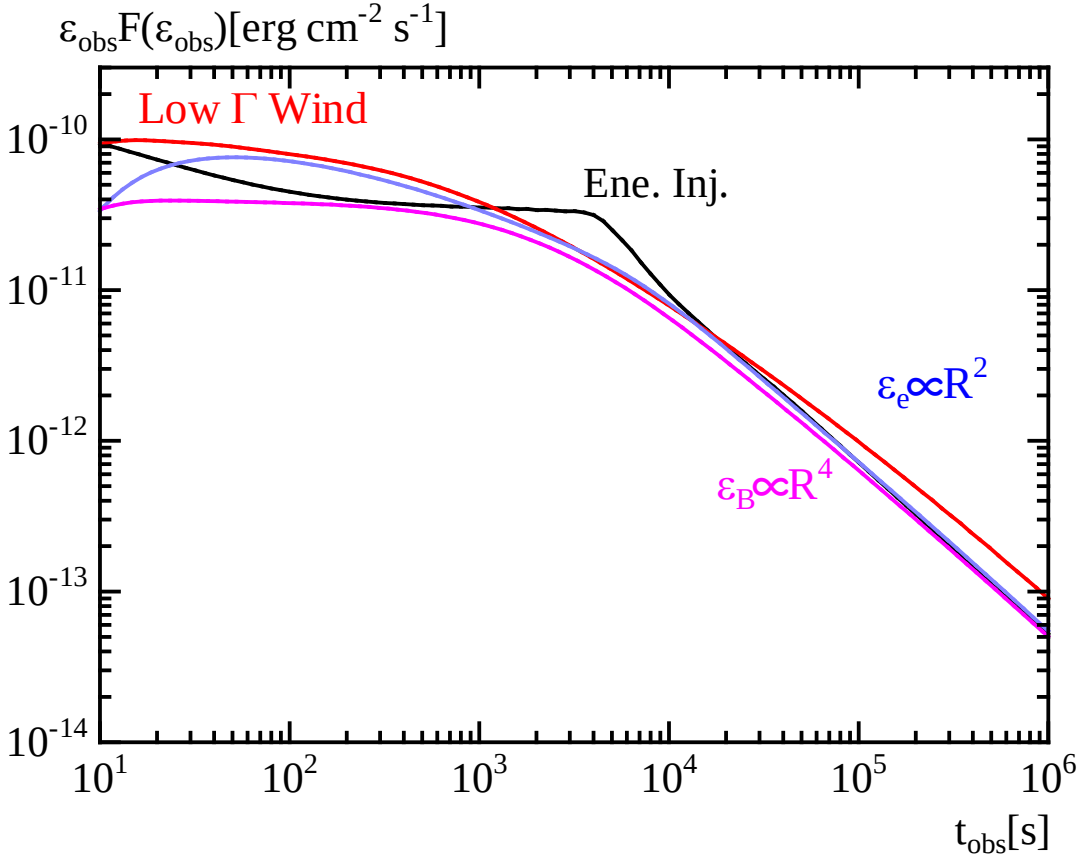




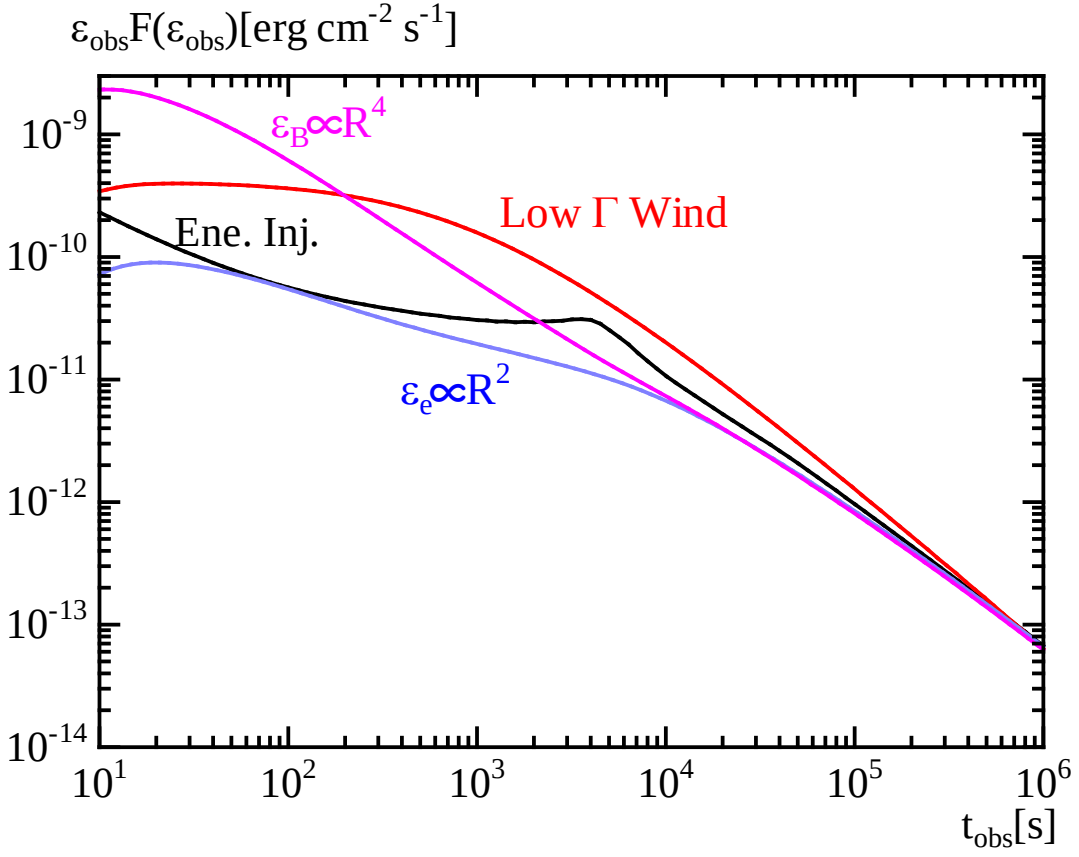
Evolution of Microscopic Parameters

Lightcurves

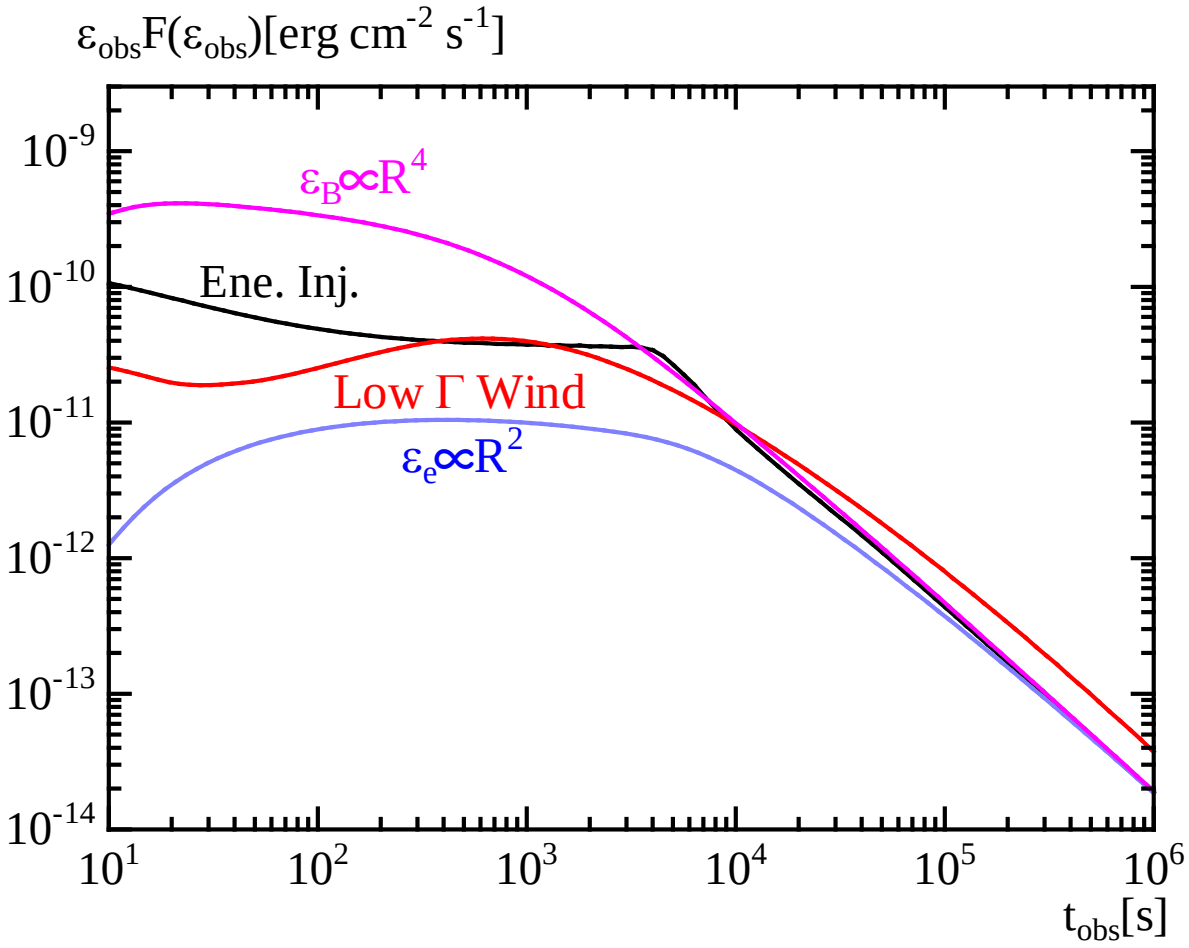
X-ray (1keV)

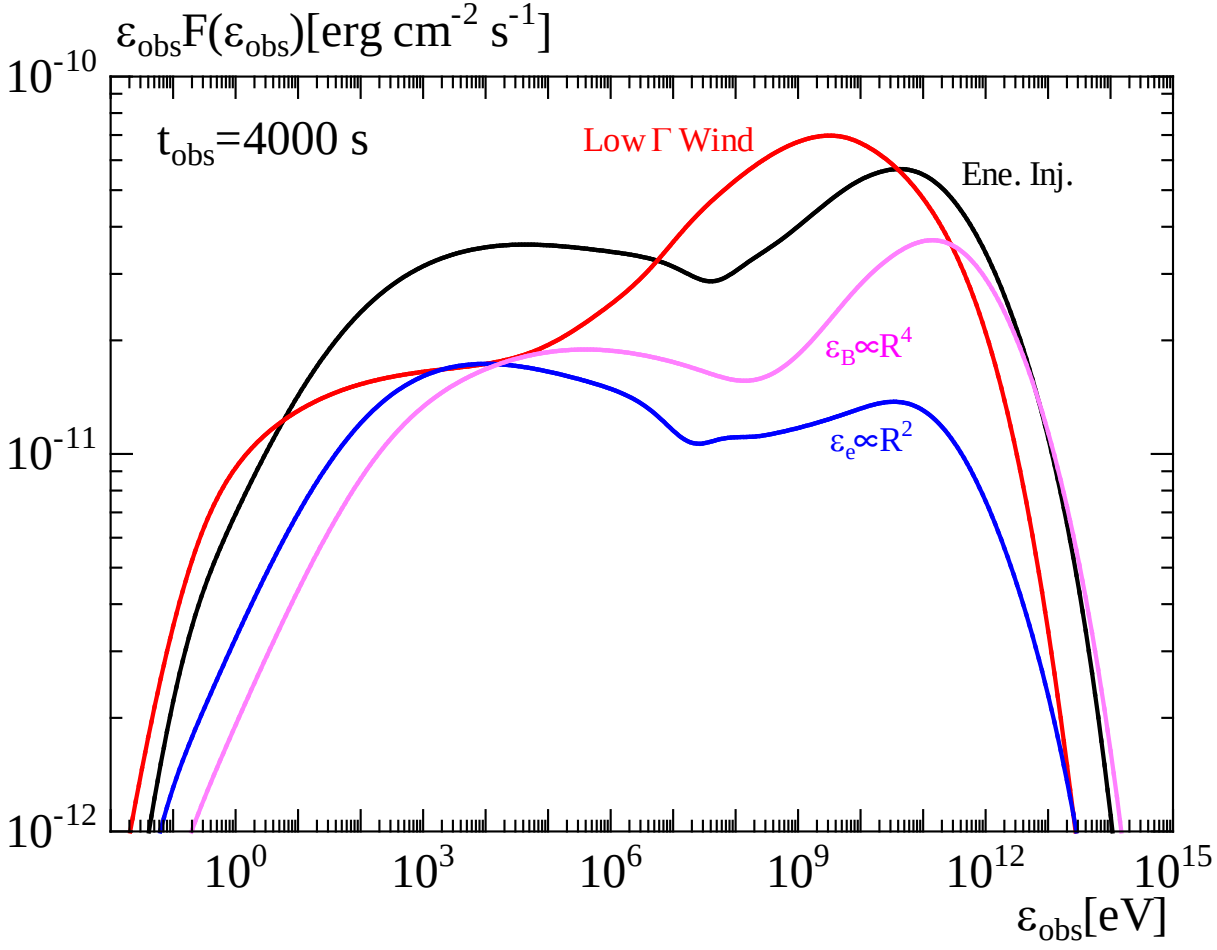


100 MeV

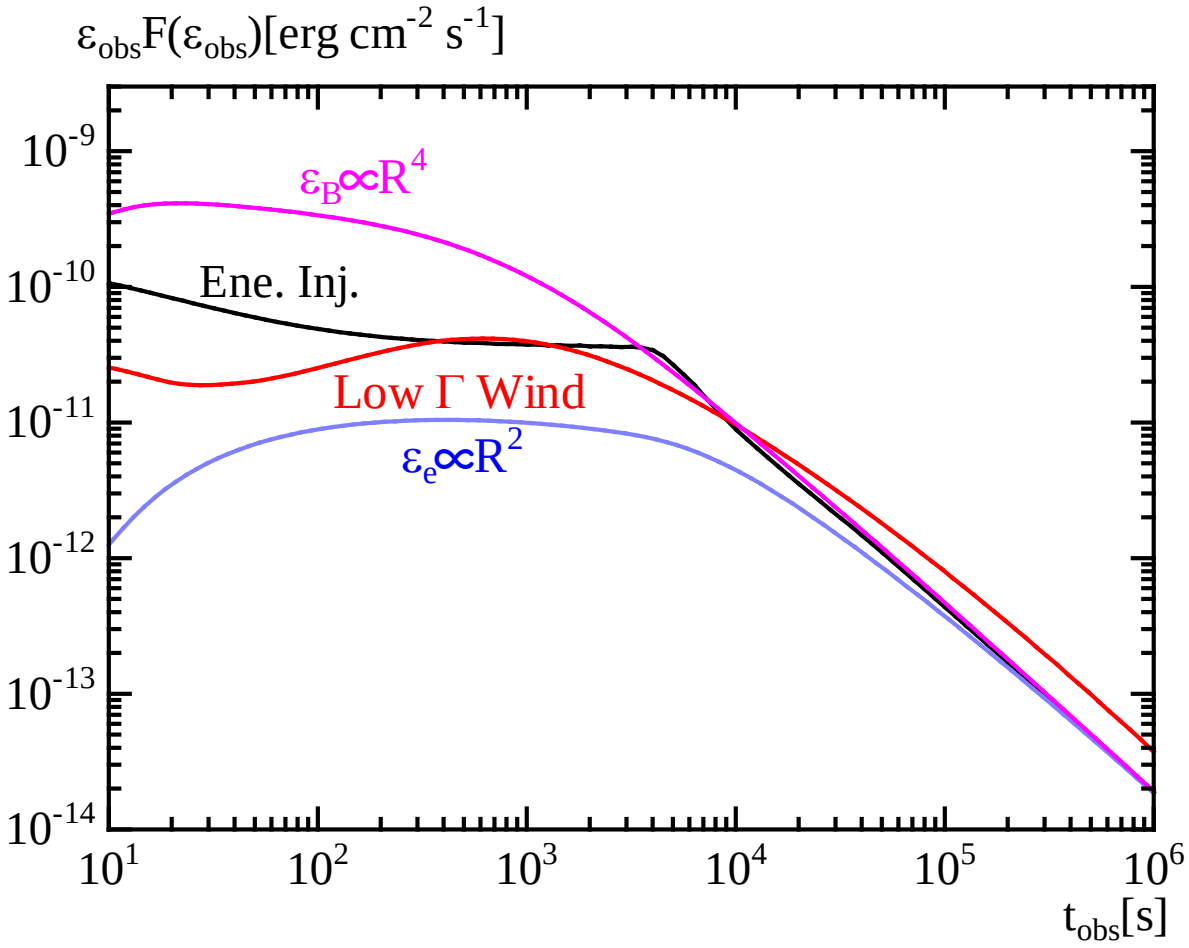


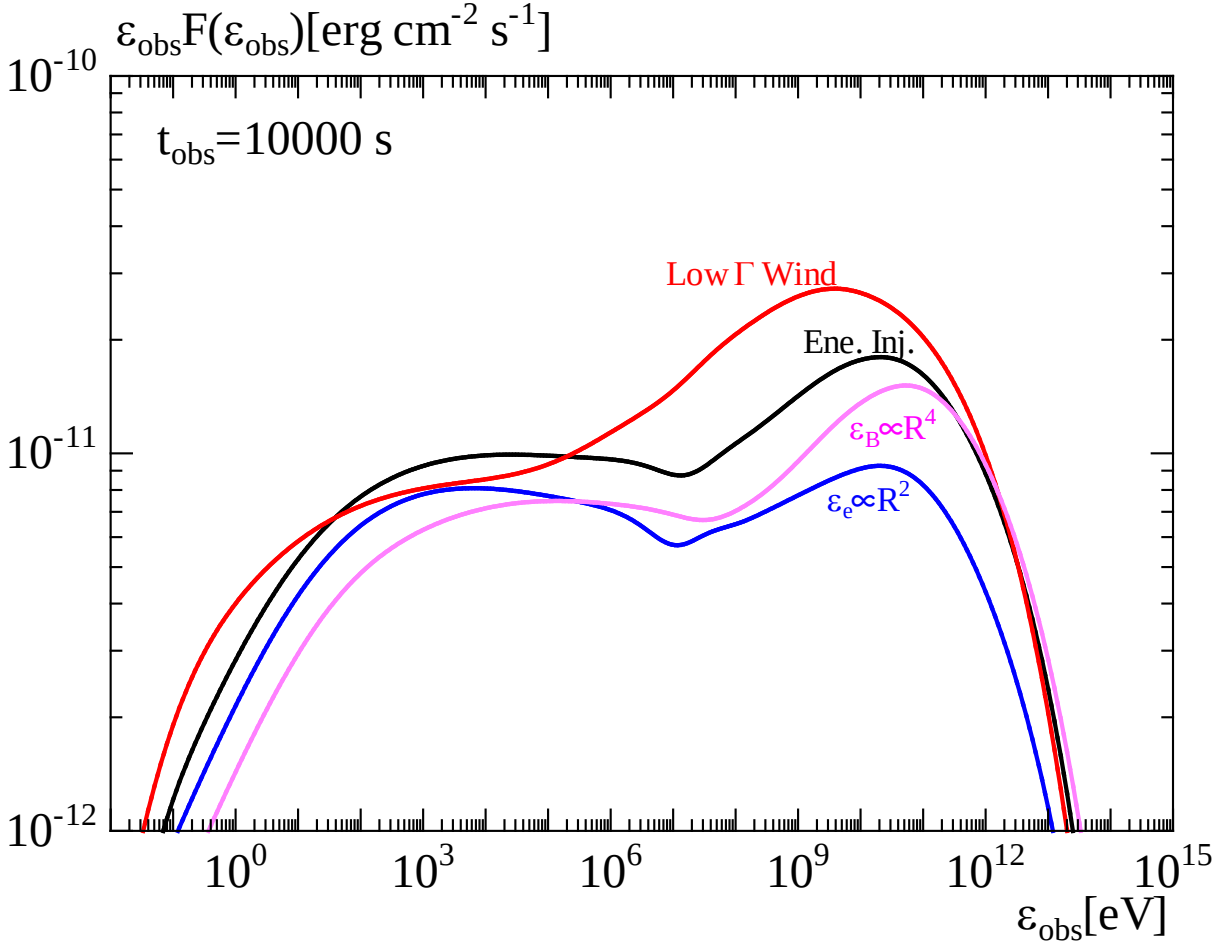
TeV Lightcurves





TeV Lightcurves





Summary

- Particle Acceleration seems faster than that in PIC simulations.
- All electrons are accelerated? No Thermal Signature.
- Future: Gamma-ray detection constrains model of shallow decay.