Multi-wavelength lightcurves of the shallow decay phase in GRB afterglows

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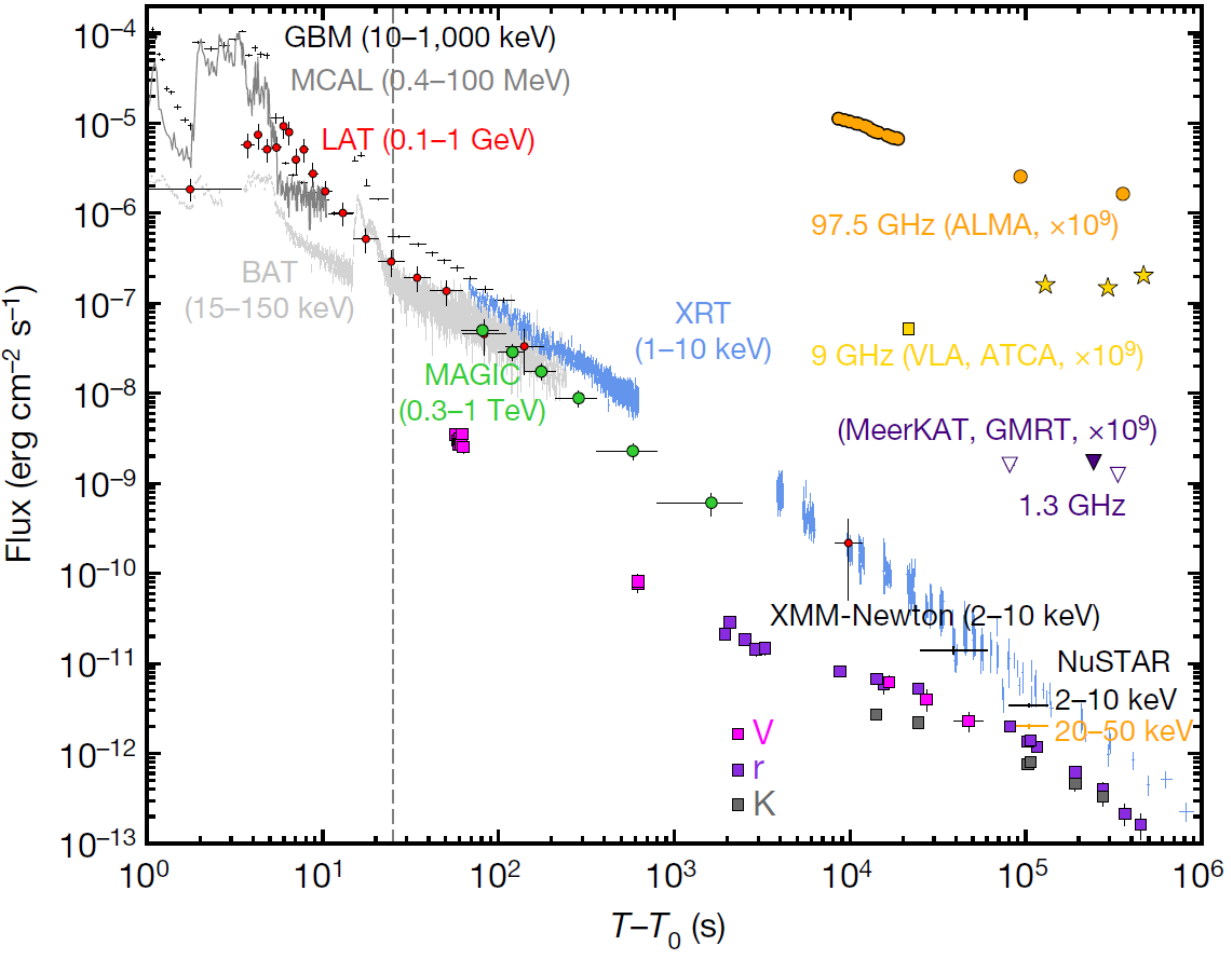
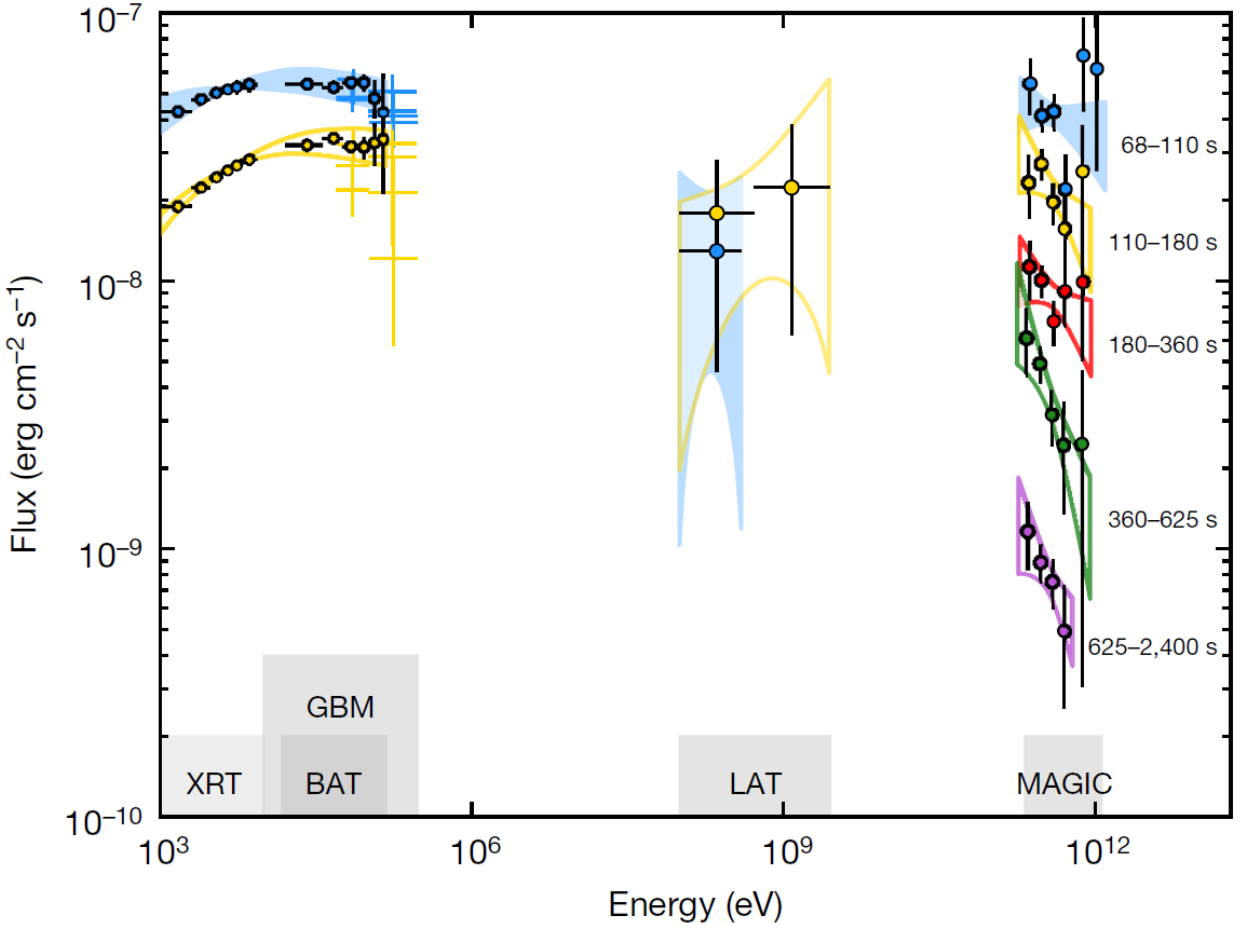
Inverse Compton in Afterglow (Ultra-relativistic Shock)

GRB 190114C



Lightcurves

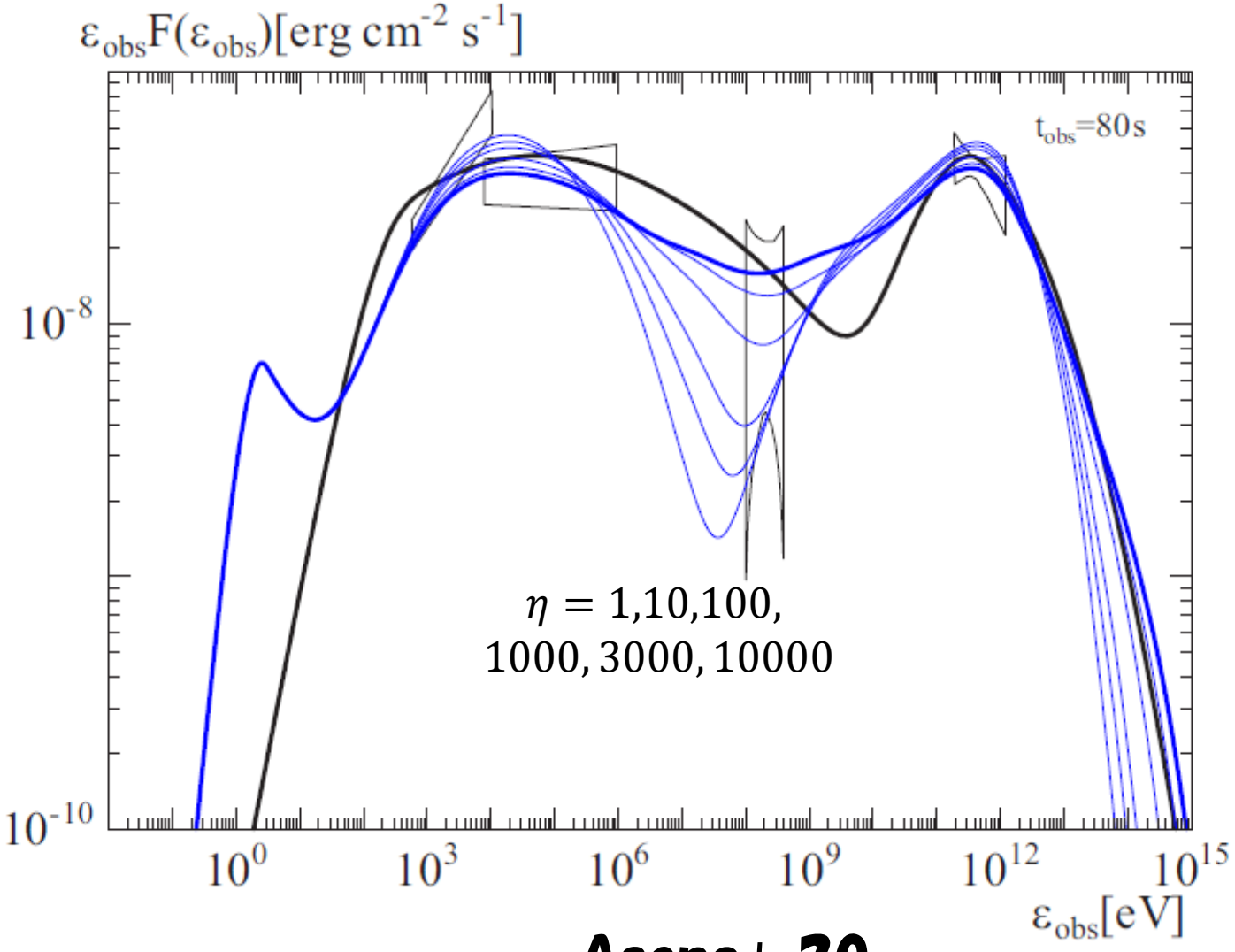


Corrected for EBL abs.

Acceleration Efficiency

Model	E_0 [erg]	Γ_0	n_0 [$\mathrm{cm^{-3}}$]	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



Asano+ 20

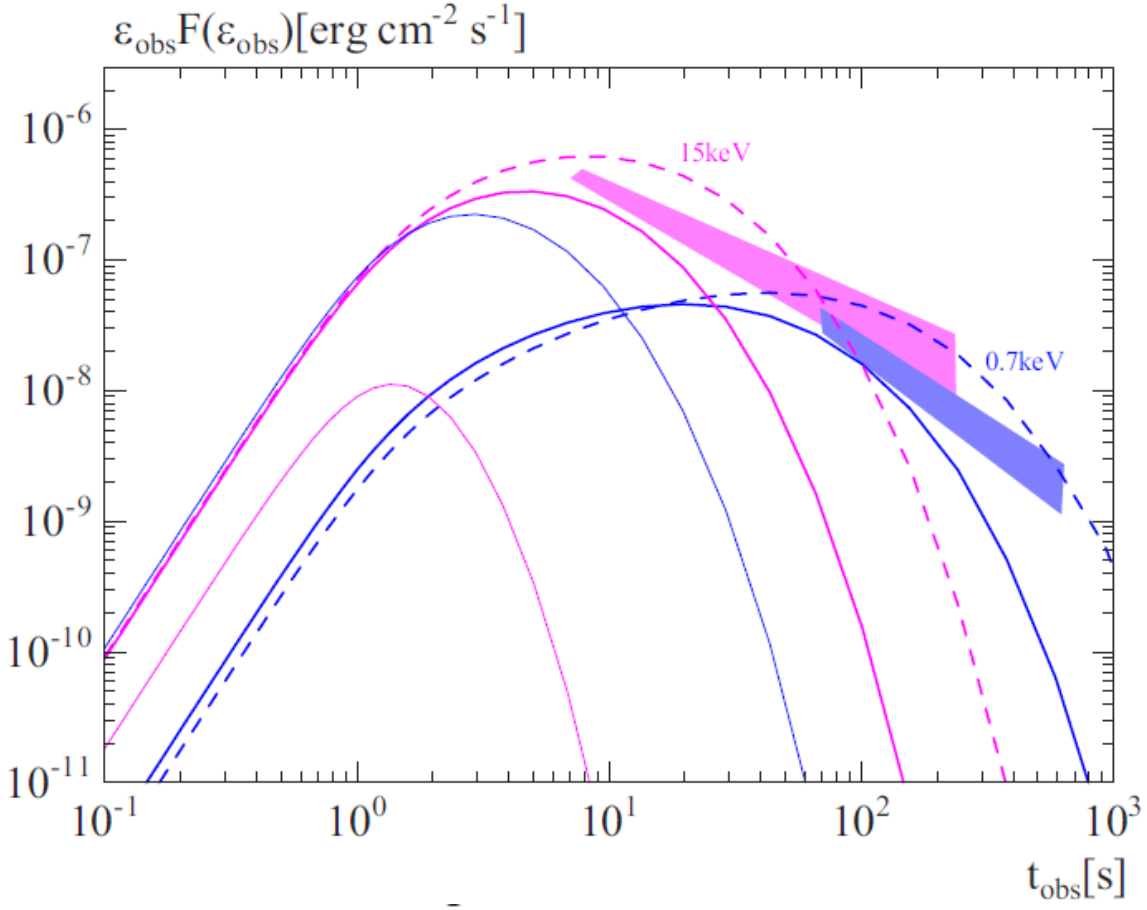
$$t_{\mathrm{acc}} \sim \eta \frac{r_L}{c}$$

$$\eta < 100$$

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

Thermal Electron Fraction

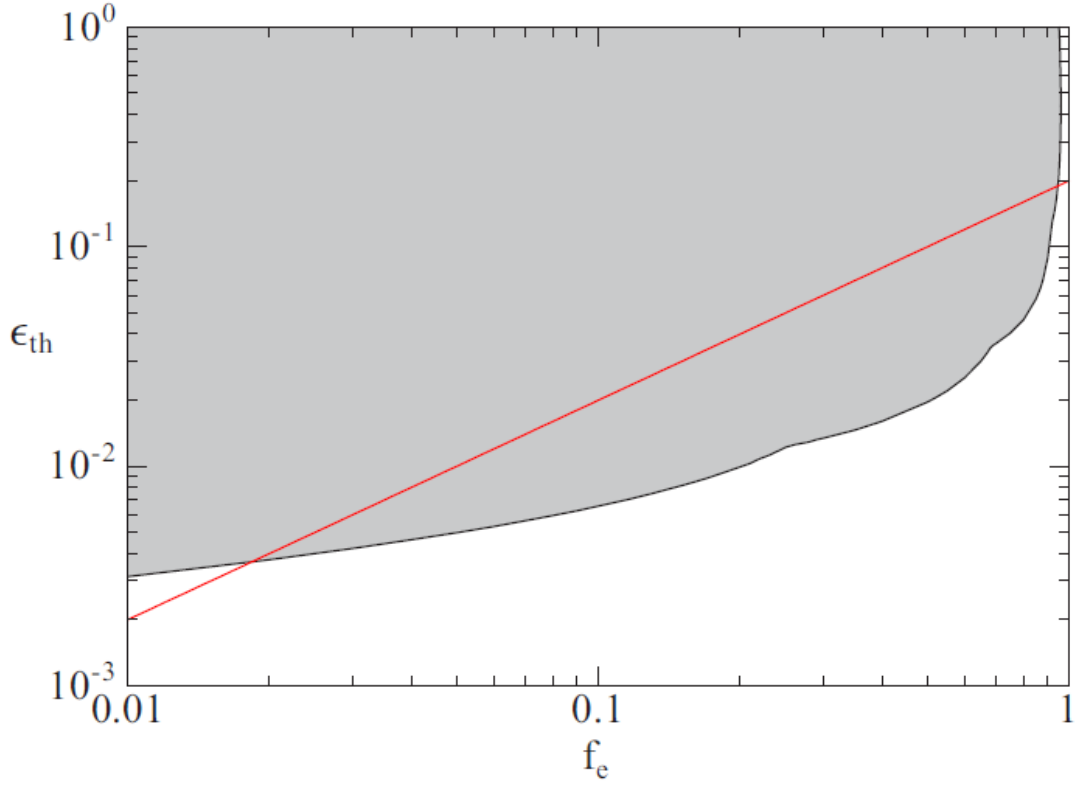
Upper Limit for thermal synchrotron



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

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

Number fraction of accelerated electrons: f_e
Pre-heating efficiency: ϵ_{th}



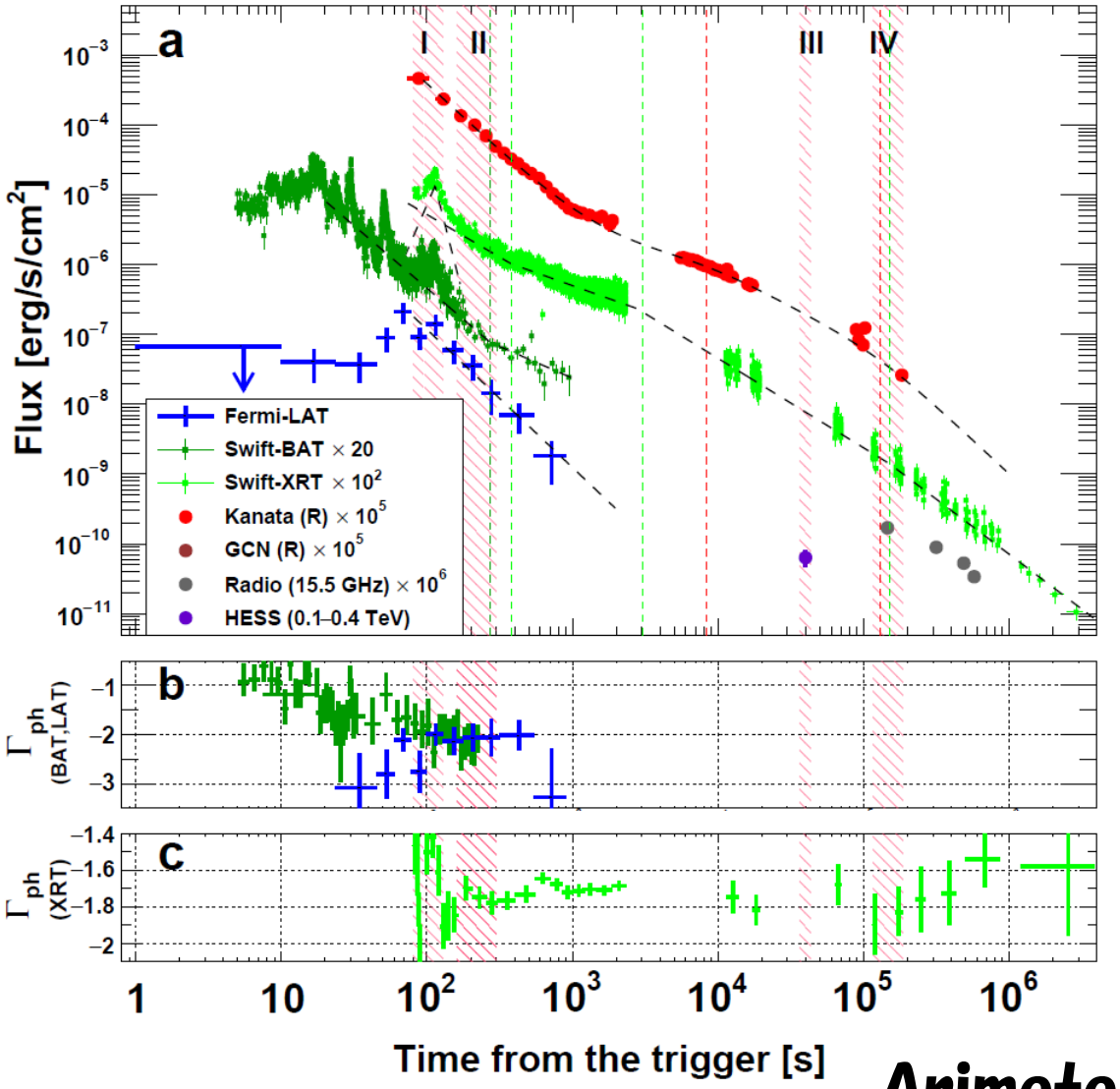
PIC simulations suggest $f_e = 0.01 - 0.1$

$\epsilon_{th} \sim 0.3$

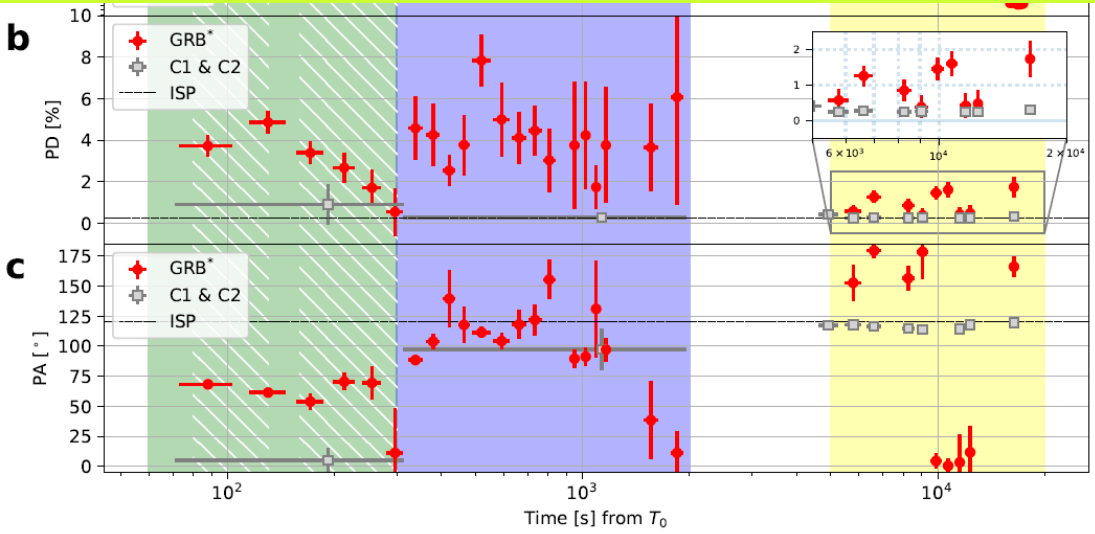
All electrons are accelerated?

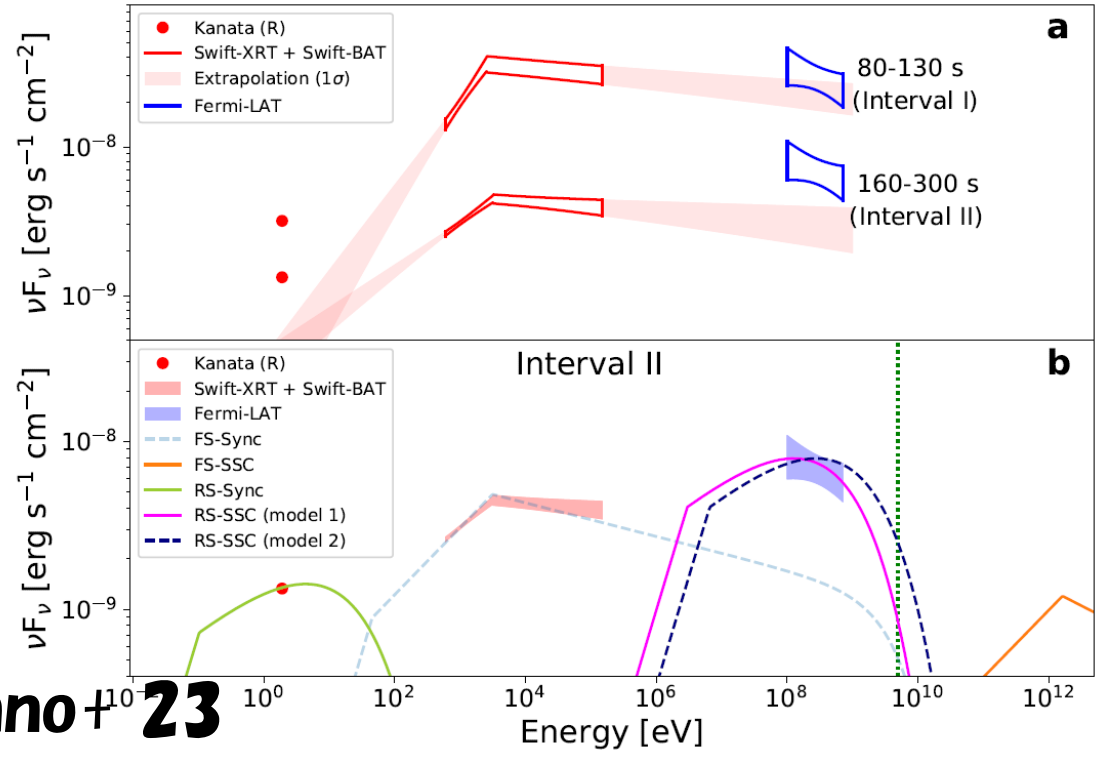
GeV Reverse Shock Emission

GRB 180720B



Optical Polarization





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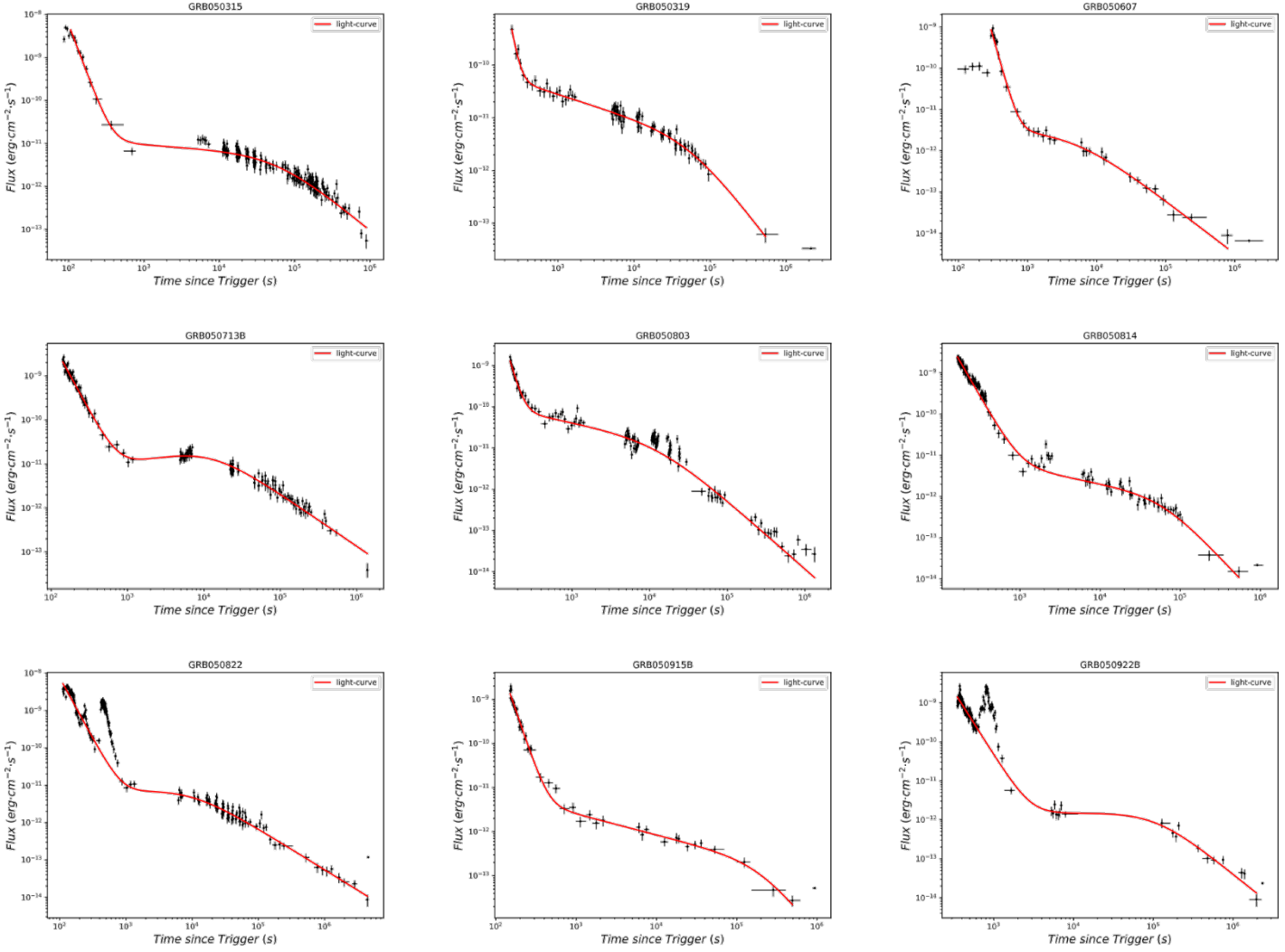
Shallow Decay Phase

X-ray LCs



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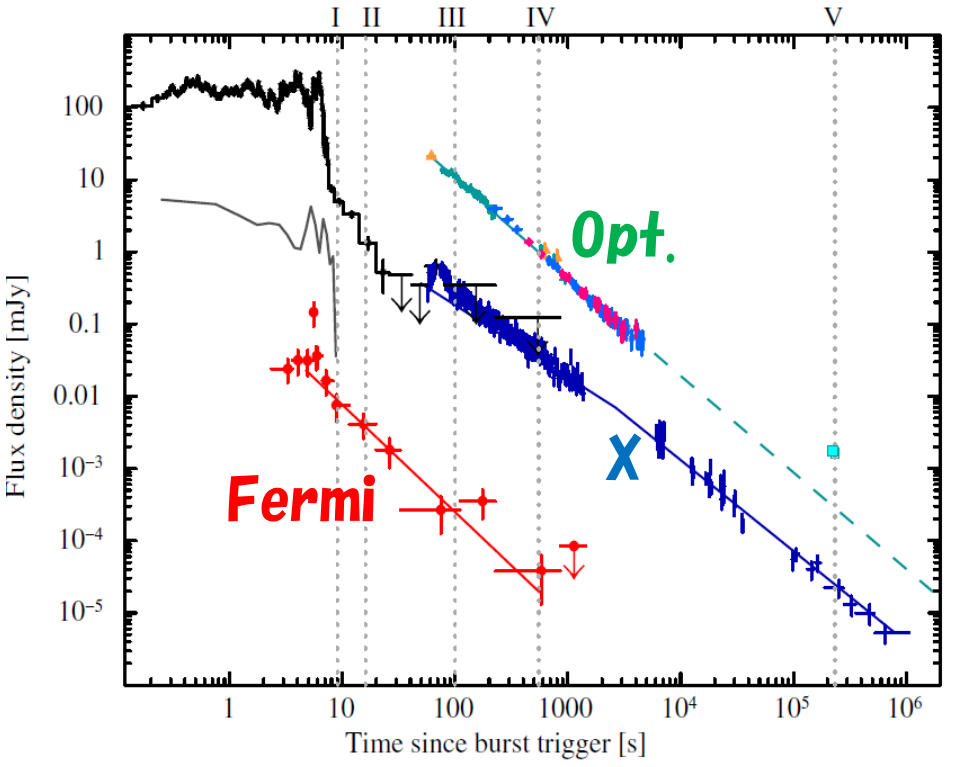
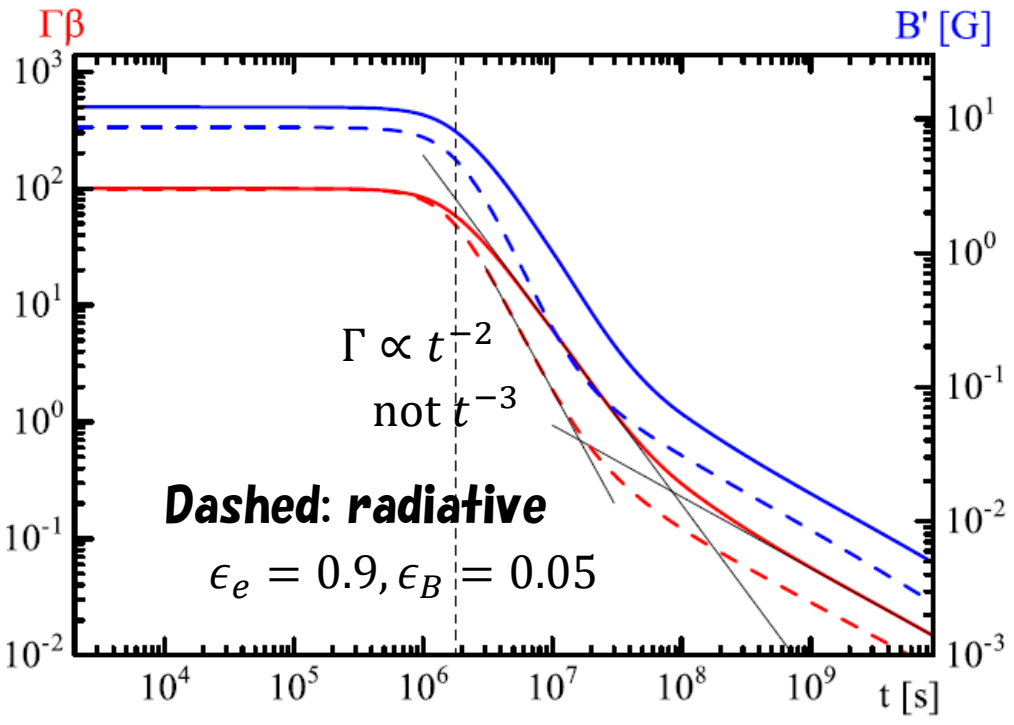
GRB 110731A (Ackerman+13)



Fermi-LAT GRBs tend to show no shallow decay.

See Yamazaki+ 20

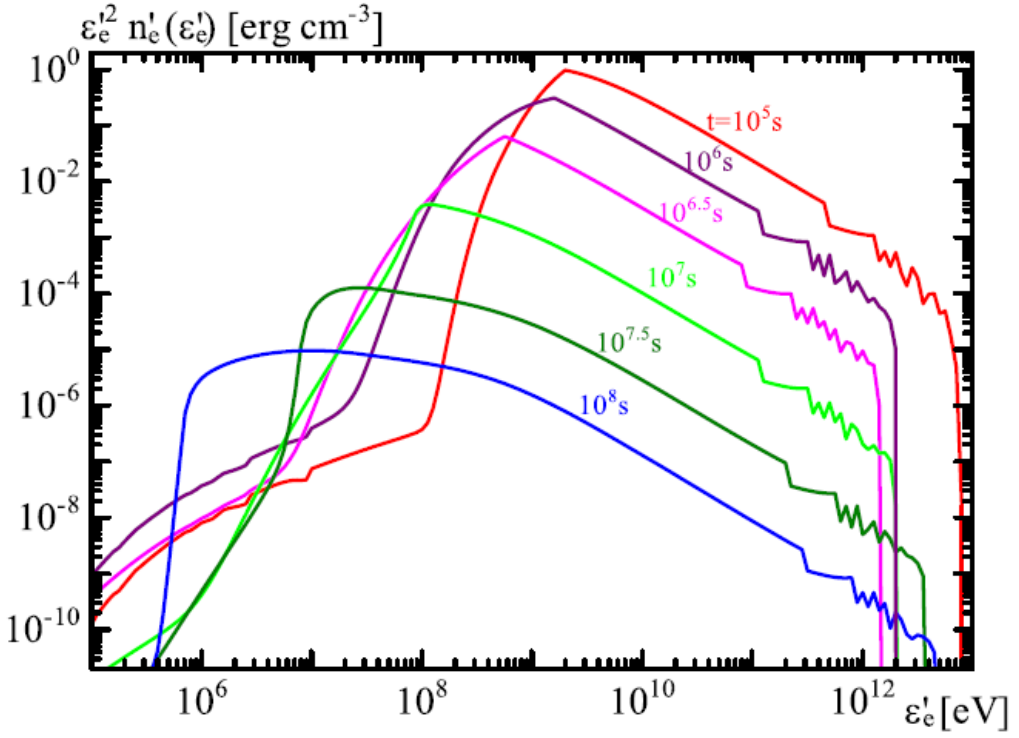
1D time-dependent calculation

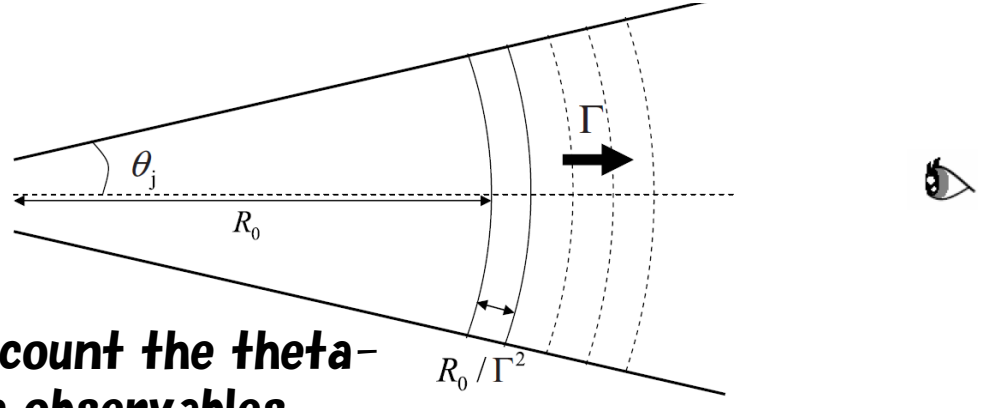


$E_0 = 10^{52}\mathrm{erg}, \Gamma_0 = 100, n_{\mathrm{ISM}} = 1\mathrm{cm}^{-3}, p = 2.2,$
$\epsilon_e = \epsilon_B = 0.1$

Fukushima, KA+ 2017

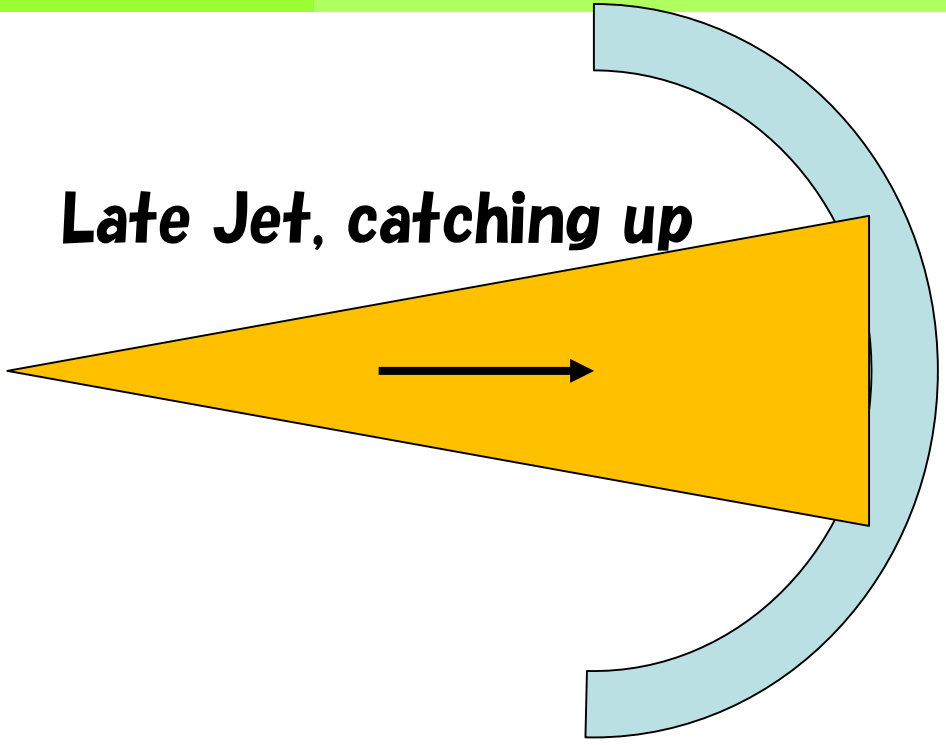
Electron energy distribution

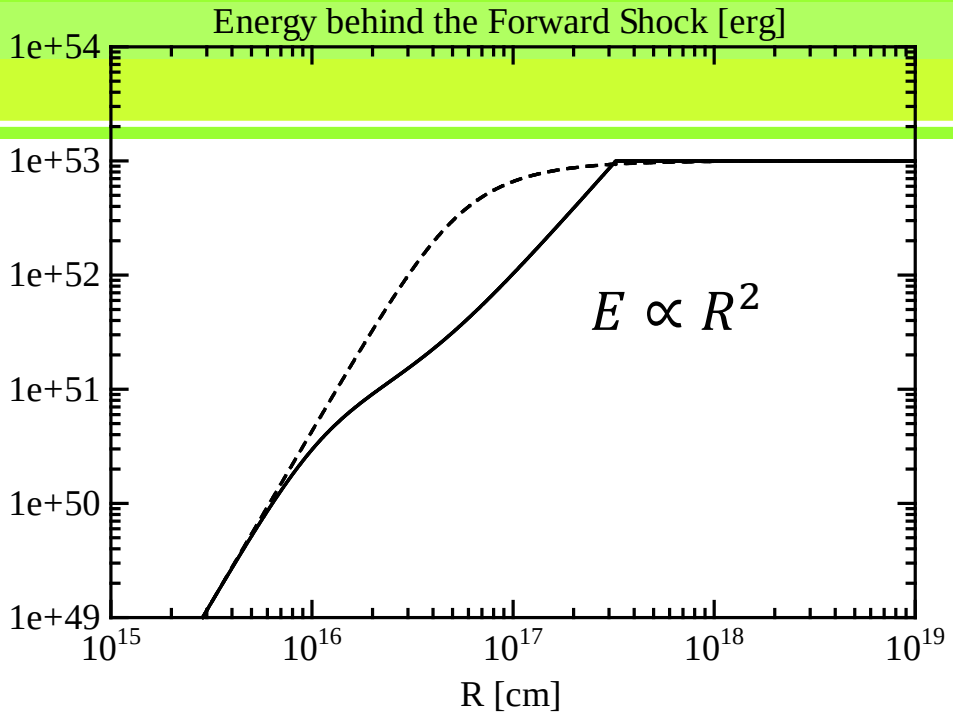


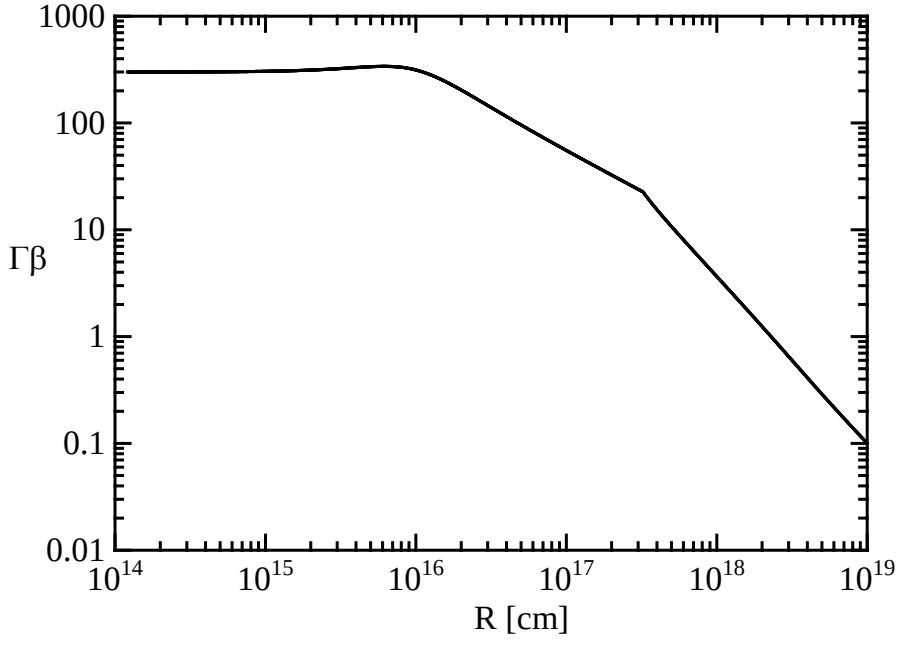


Taking into account the theta-dependence on observables.

Energy Injection Model



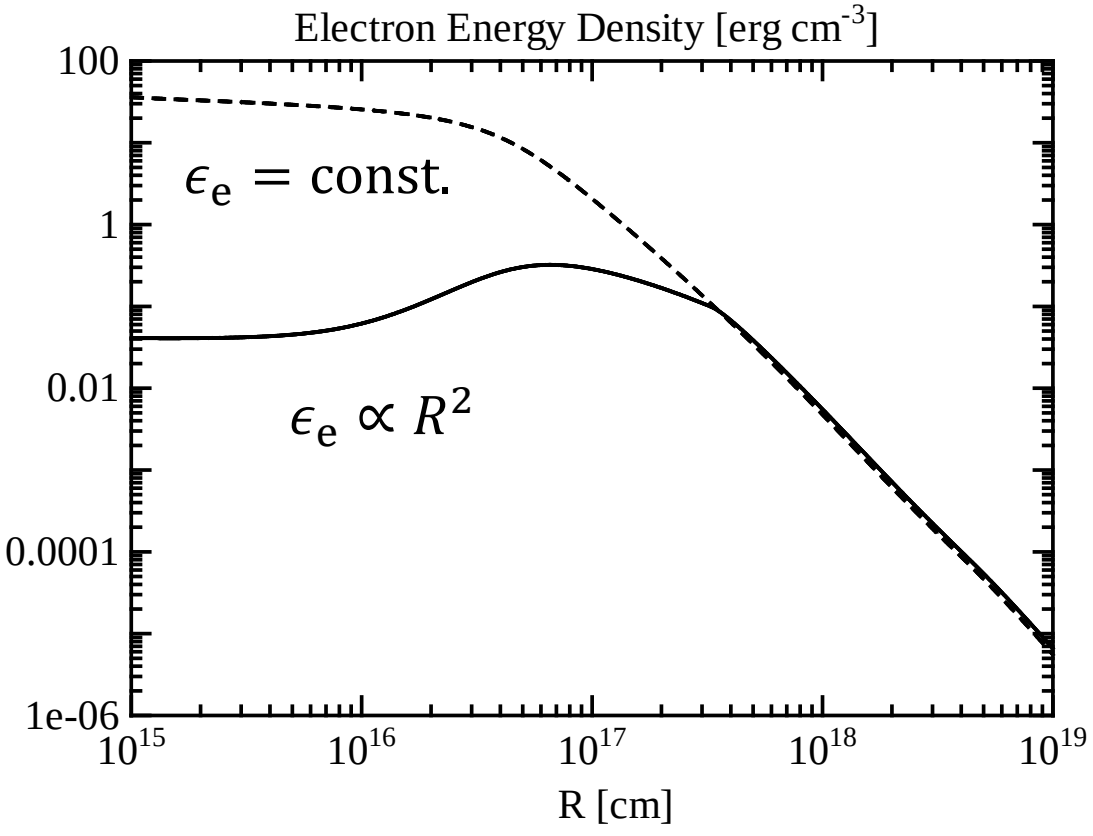




Phenomenological Model

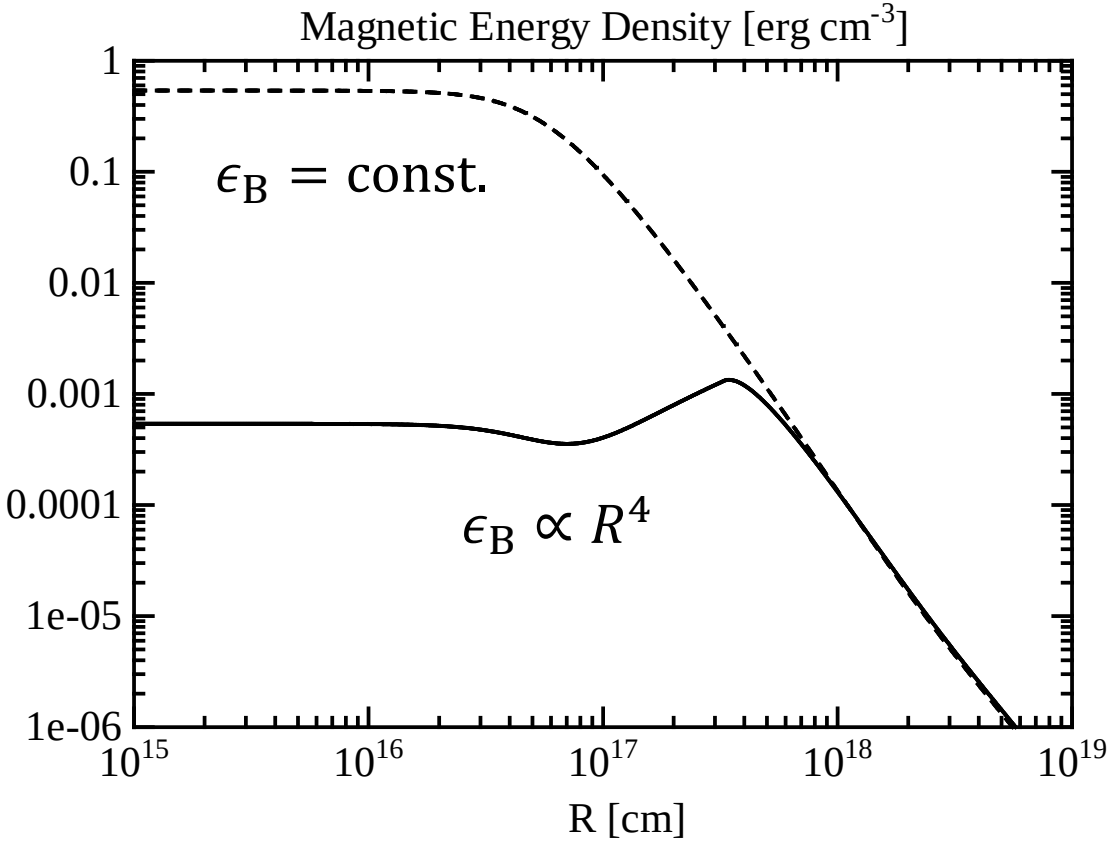
$\epsilon_e \propto R^2$ for $R < 3.2 \times 10^{17}$cm

$10^{-4} \rightarrow 10^{-1}$



$\epsilon_B \propto R^4$ for $R < 3.2 \times 10^{17}$cm

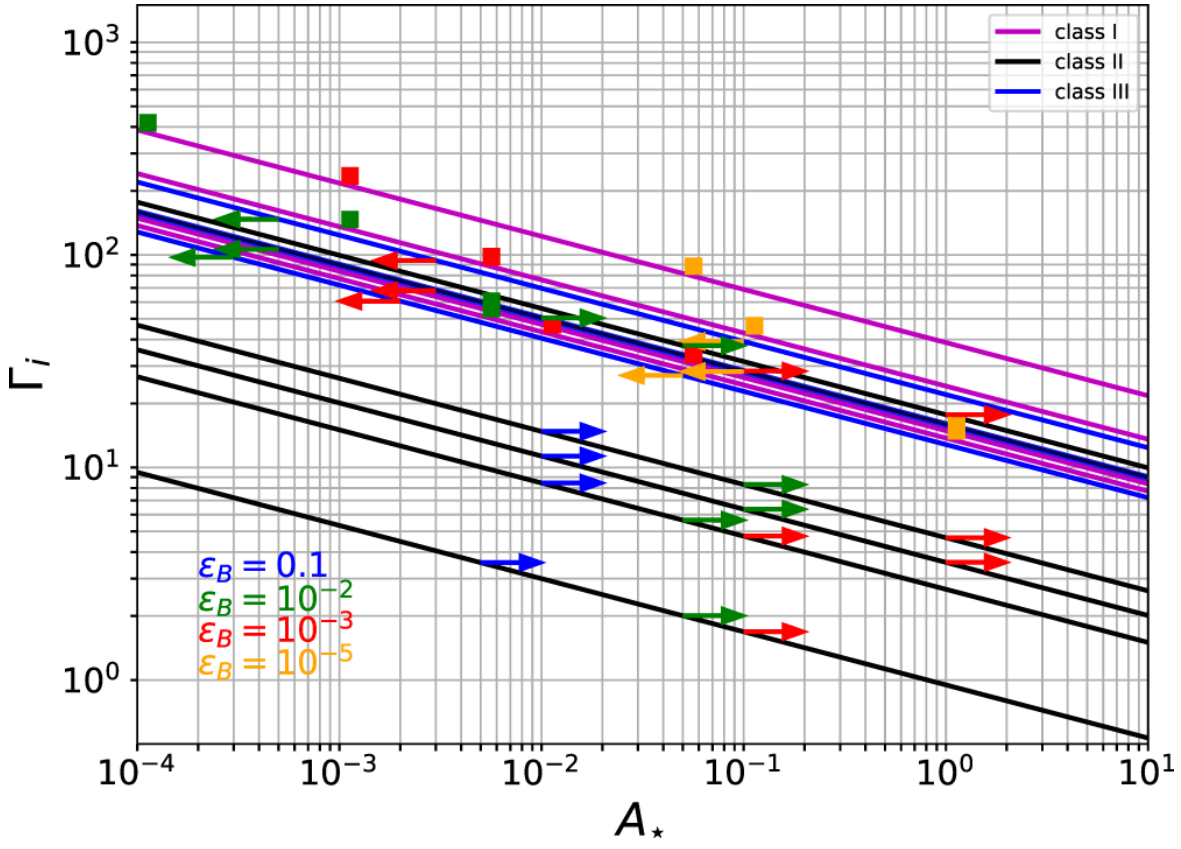
$10^{-6} \rightarrow 10^{-3}$



Low-Γ + Wind

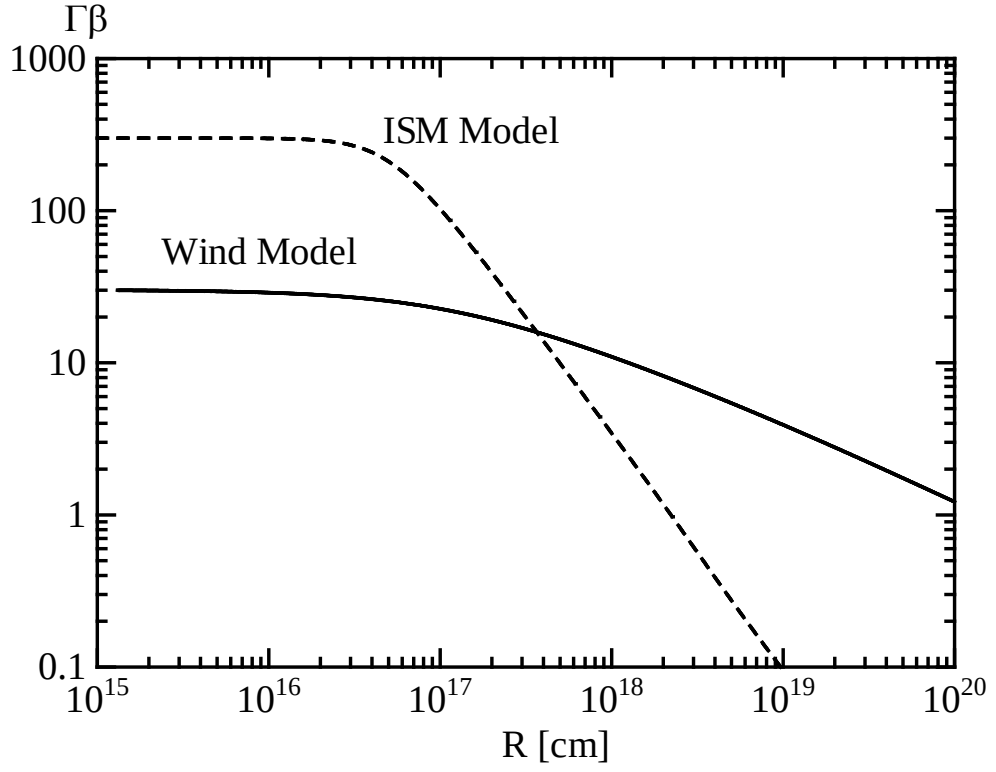
A* = 0.3

See Dereli-Bégué +22



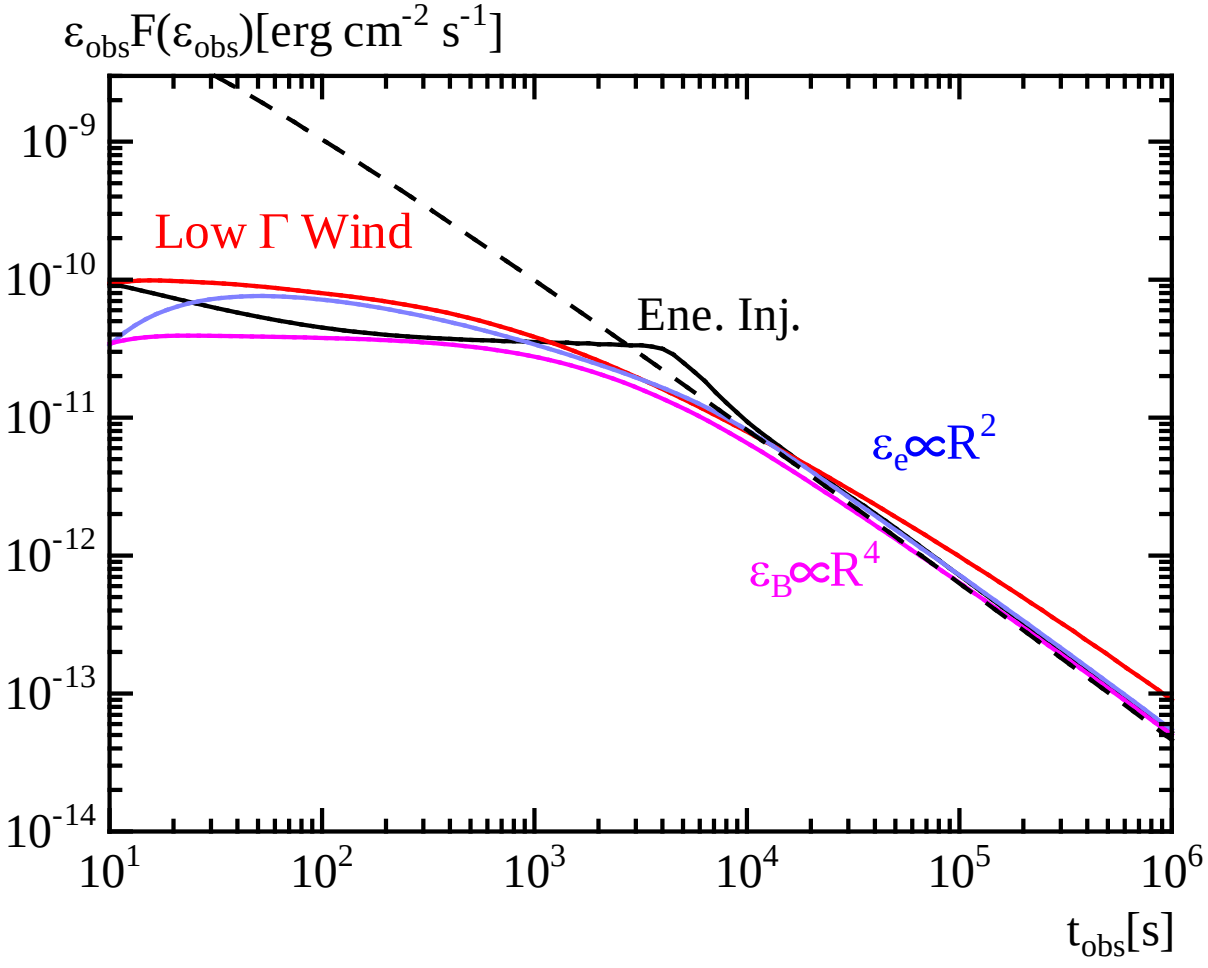
$$\rho R^2 = 1.5 \times 10^{11} \mathrm{g/cm}$$

$$\Gamma_0 = 30, E_0 = 2 \times 10^{53} \mathrm{erg}$$

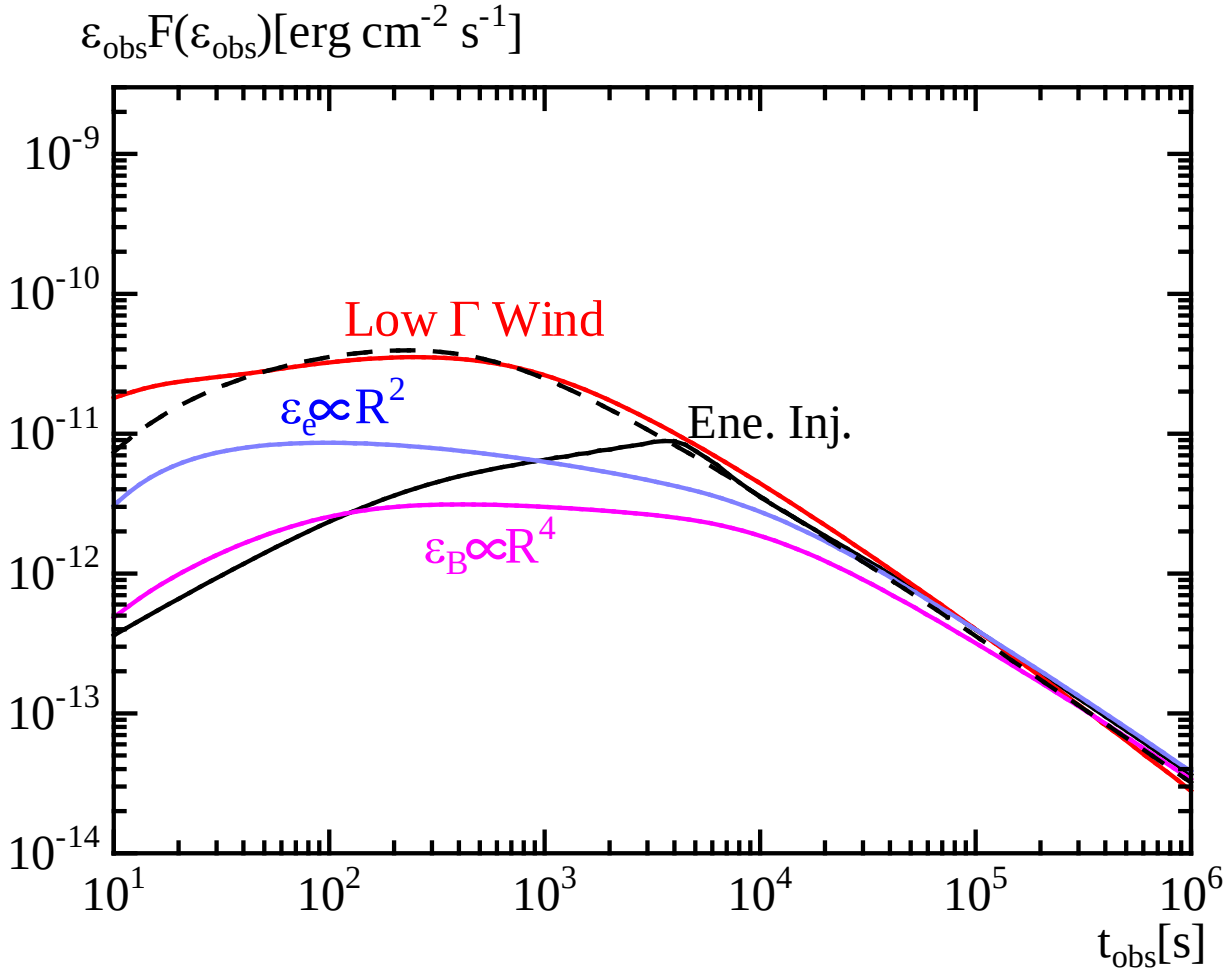


Lightcurves

X-ray (1keV)



Optical



Contamination of Reverse Shock?

Theoretical Approximation

One-to-One Correspondence

$$t_{\rm obs} \simeq (1+z)R/(4c\Gamma^2)$$

Once Γ and R are given,

$$\gamma'_{\rm m} \simeq \frac{\epsilon_{\rm e}}{\eta}\frac{p-2}{p-1}\Gamma\frac{m_{\rm p}}{m_{\rm e}}$$

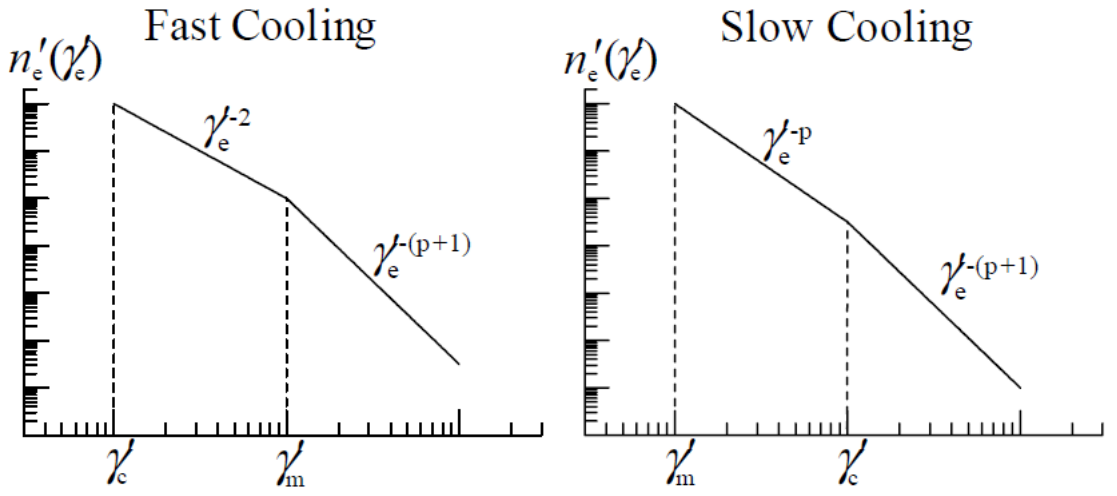
$$B' \simeq \Gamma\sqrt{32\pi\epsilon_B n_{\rm ISM} m_{\rm p} c^2}$$

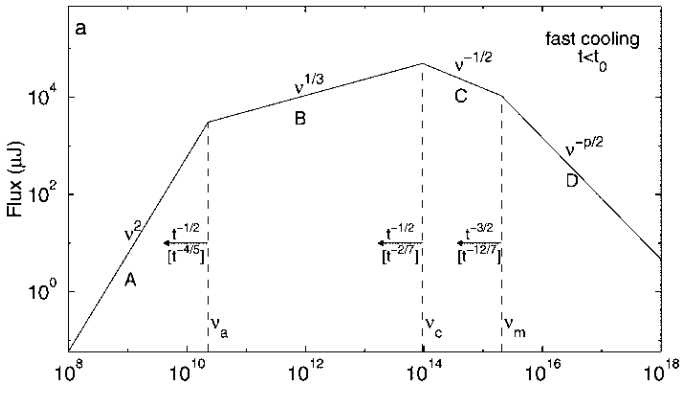
$$\gamma'_{\rm c} \simeq \frac{6\pi(1+z)m_{\rm e}c}{\sigma_{\rm T}B'^2\Gamma t_{\rm obs}}$$

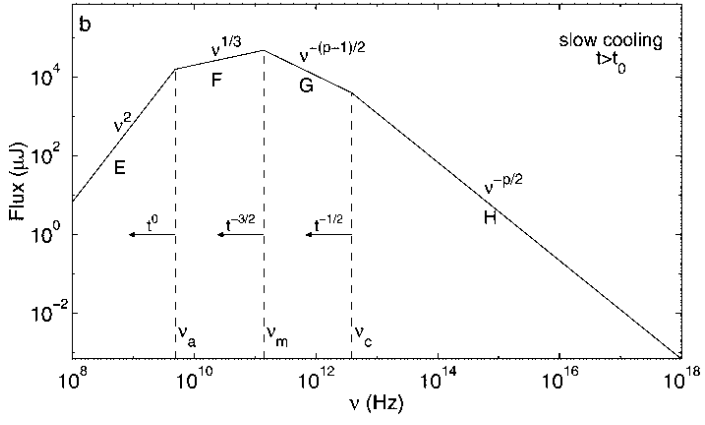
$$F_{\rm max} \simeq (1+z)\frac{N_{\rm e}}{4\pi D_{\rm L}^2}\frac{\sqrt{3}\,e^3 B'}{16\hbar m_{\rm e}c^2}\Gamma$$

All parameters we need

For a snap shot, we do not need information for evolution of shocks.

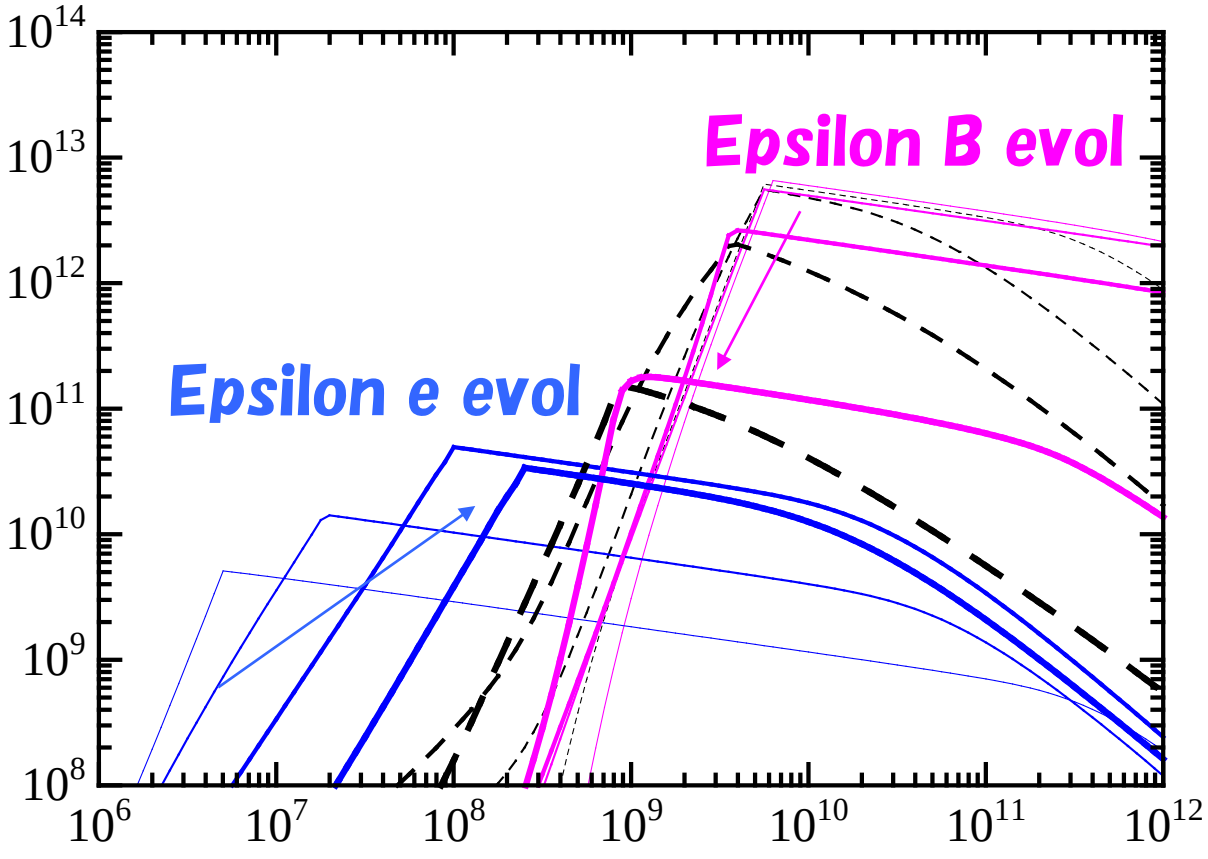




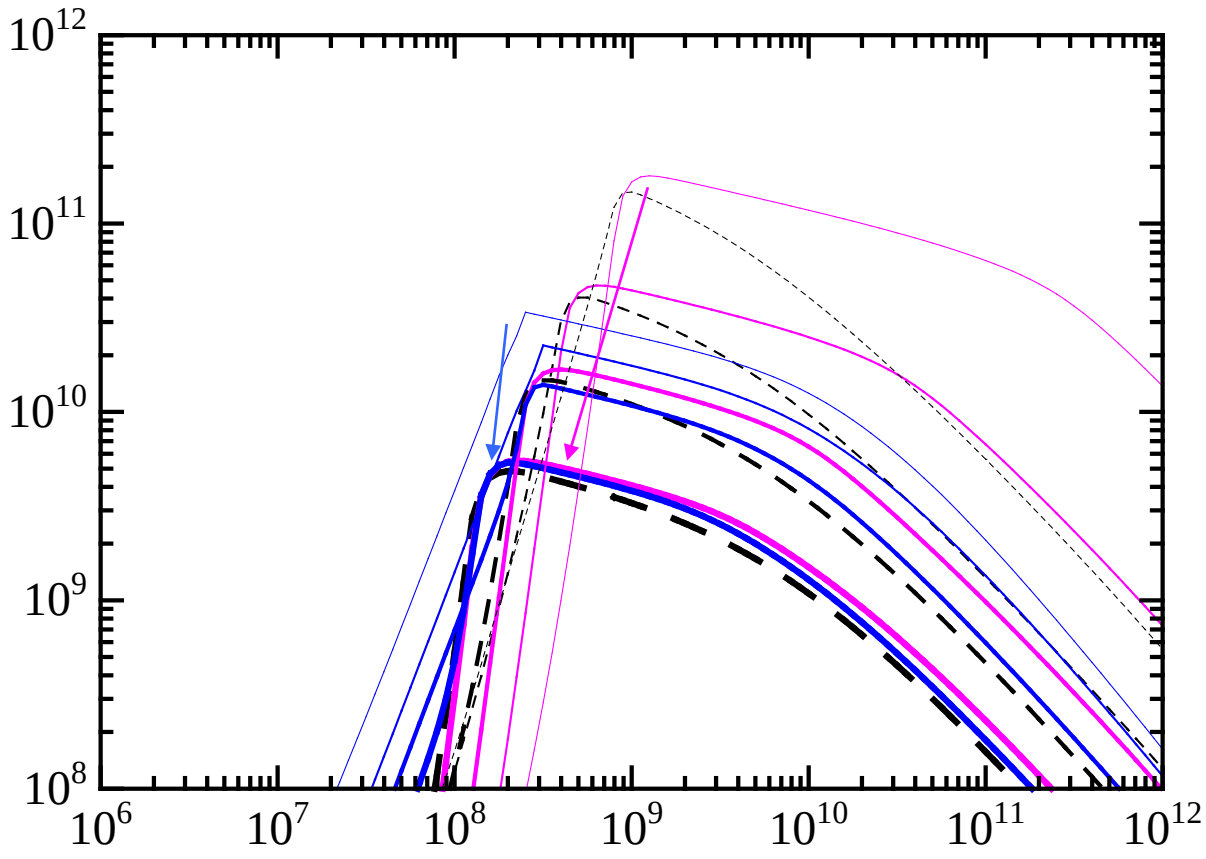


Numerical Estimate: Electron Energy Distribution

Common parameters for $\Gamma, \epsilon_e, \epsilon_B$



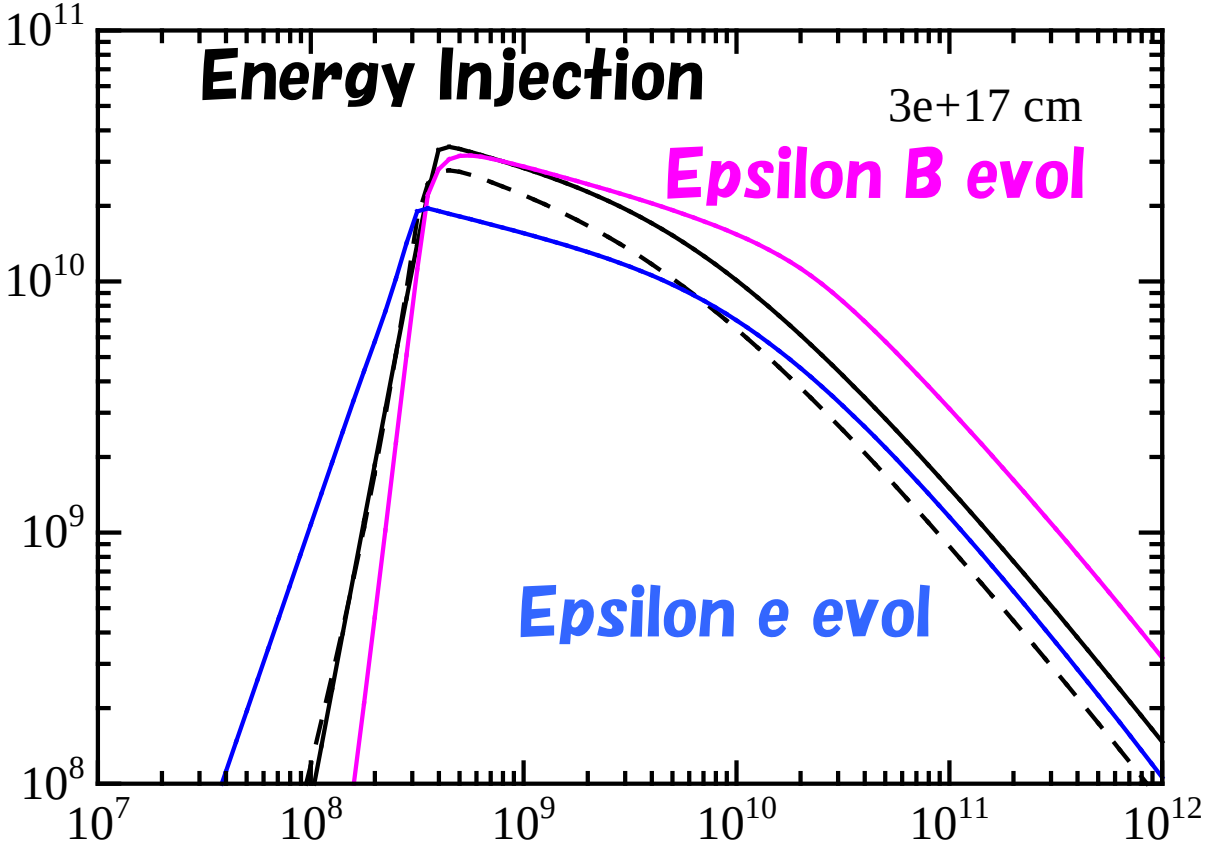
Early Stage

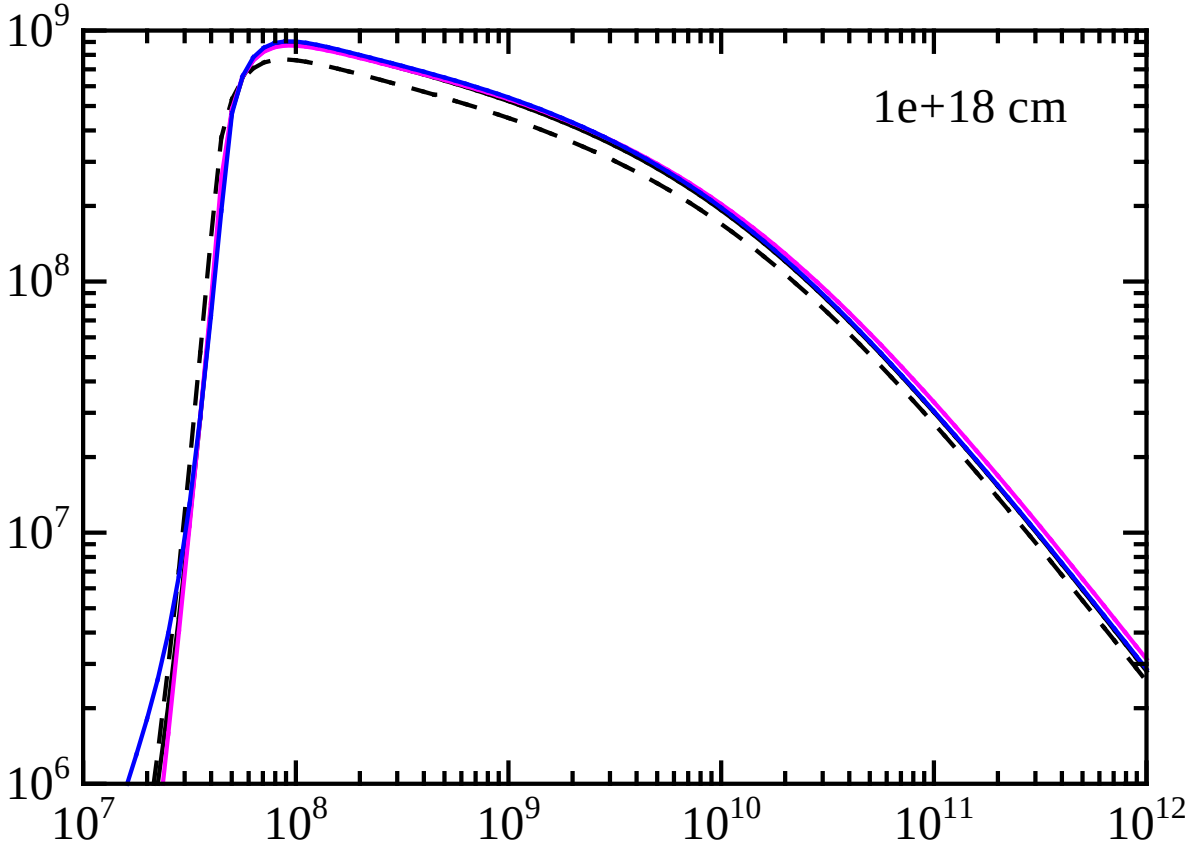


Late Stage

Numerical Estimate: Electron Energy Distribution

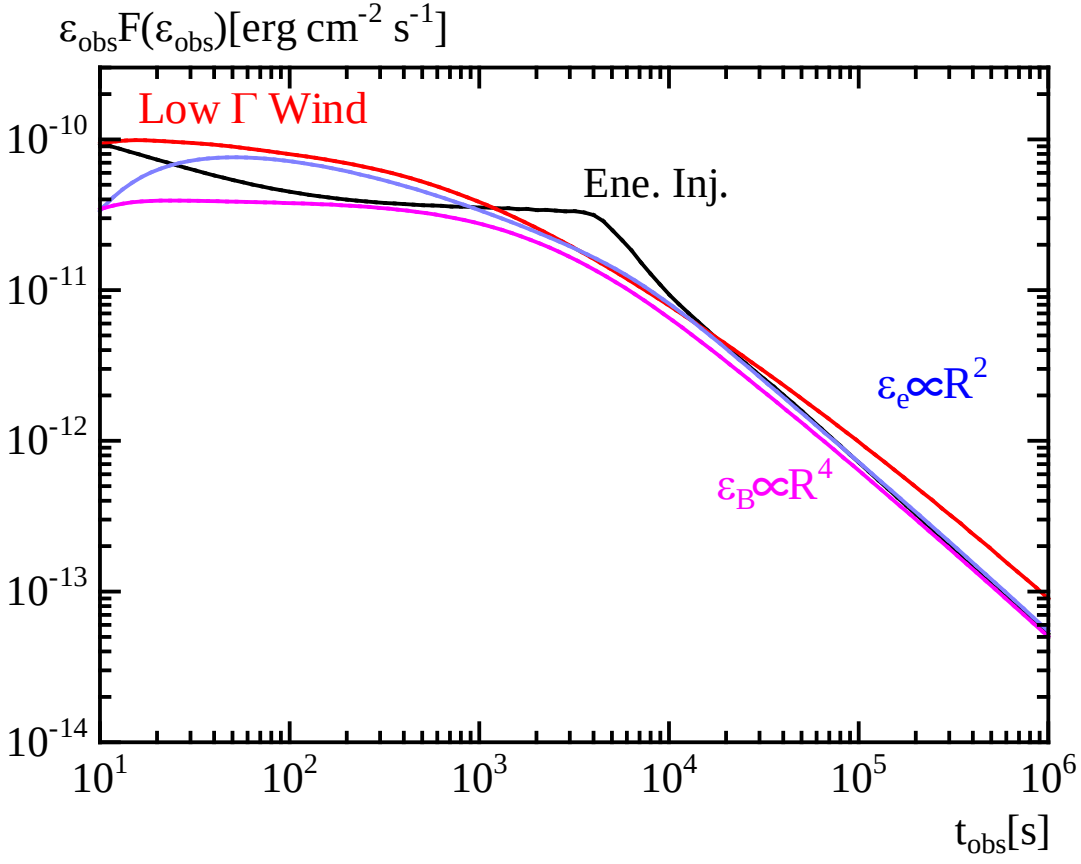
Common parameters for $\Gamma, \epsilon_e, \epsilon_B$



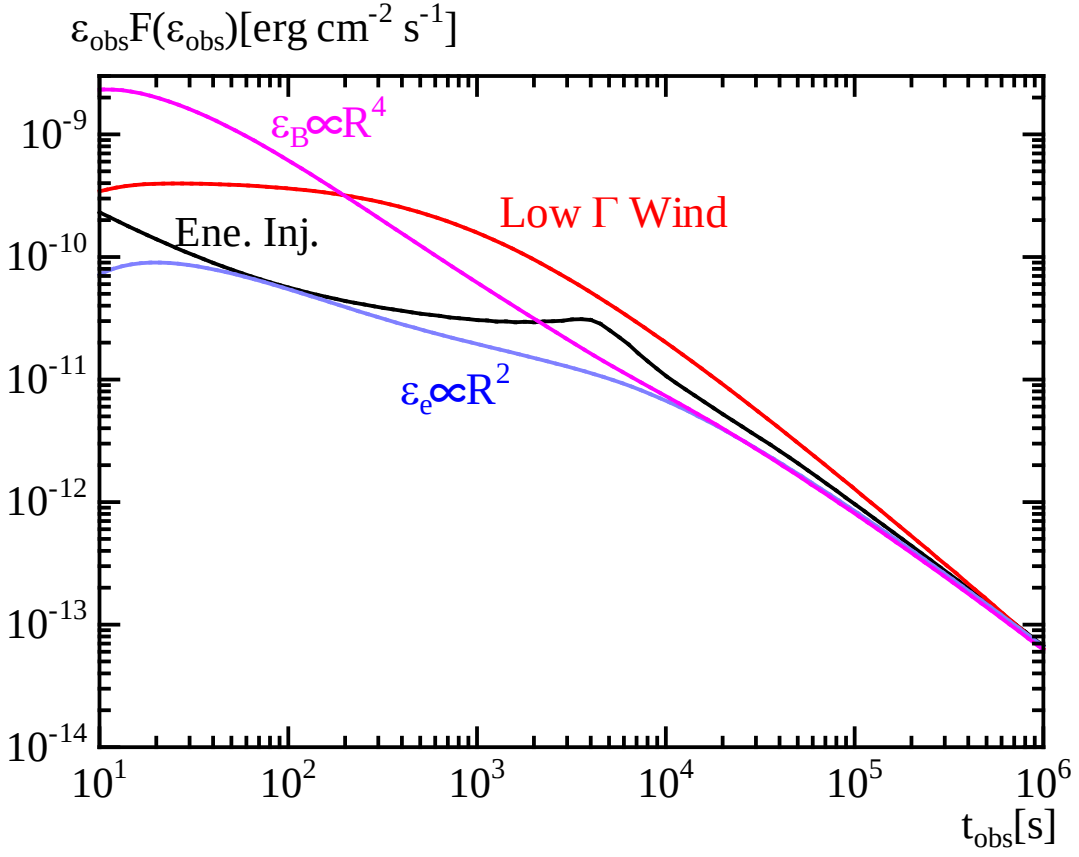


Lightcurves

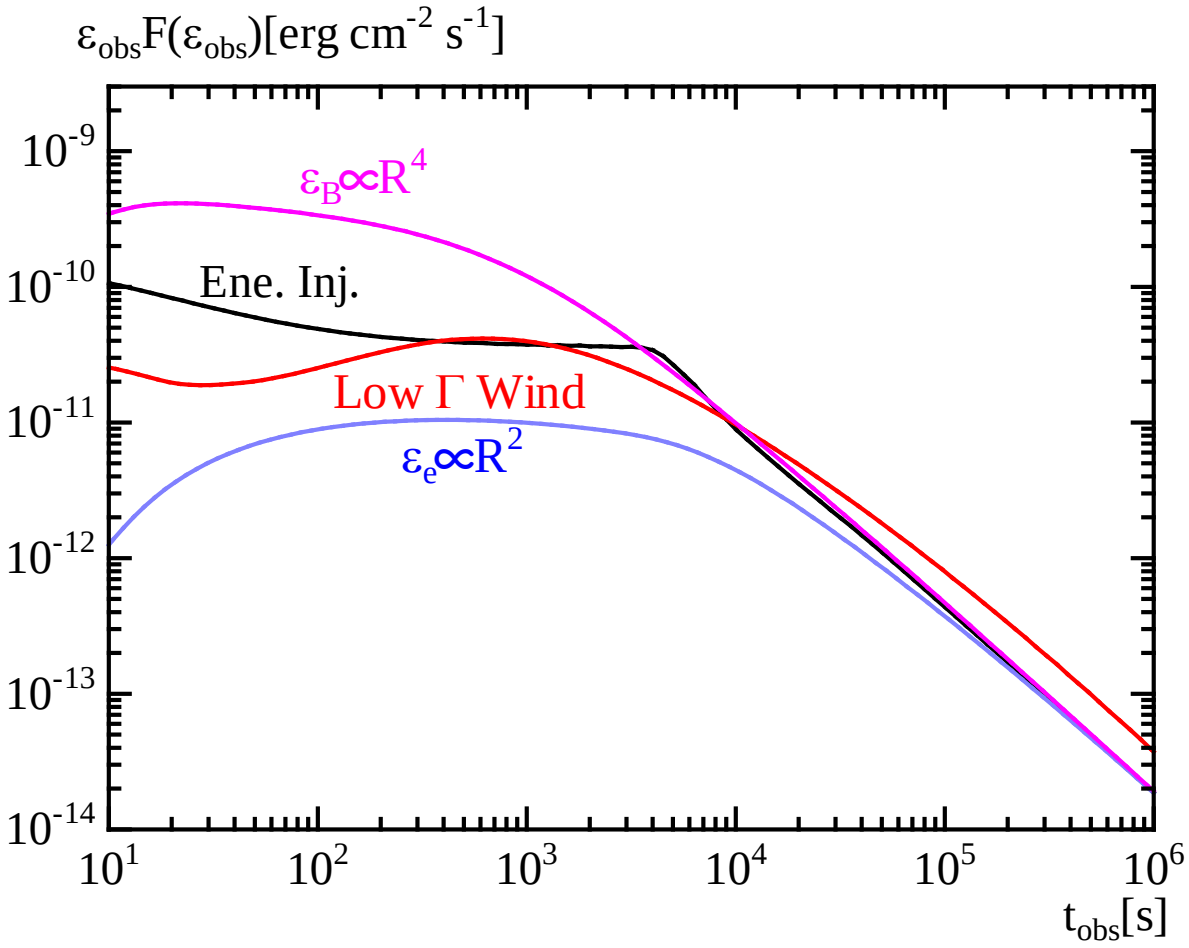
X-ray (1keV)

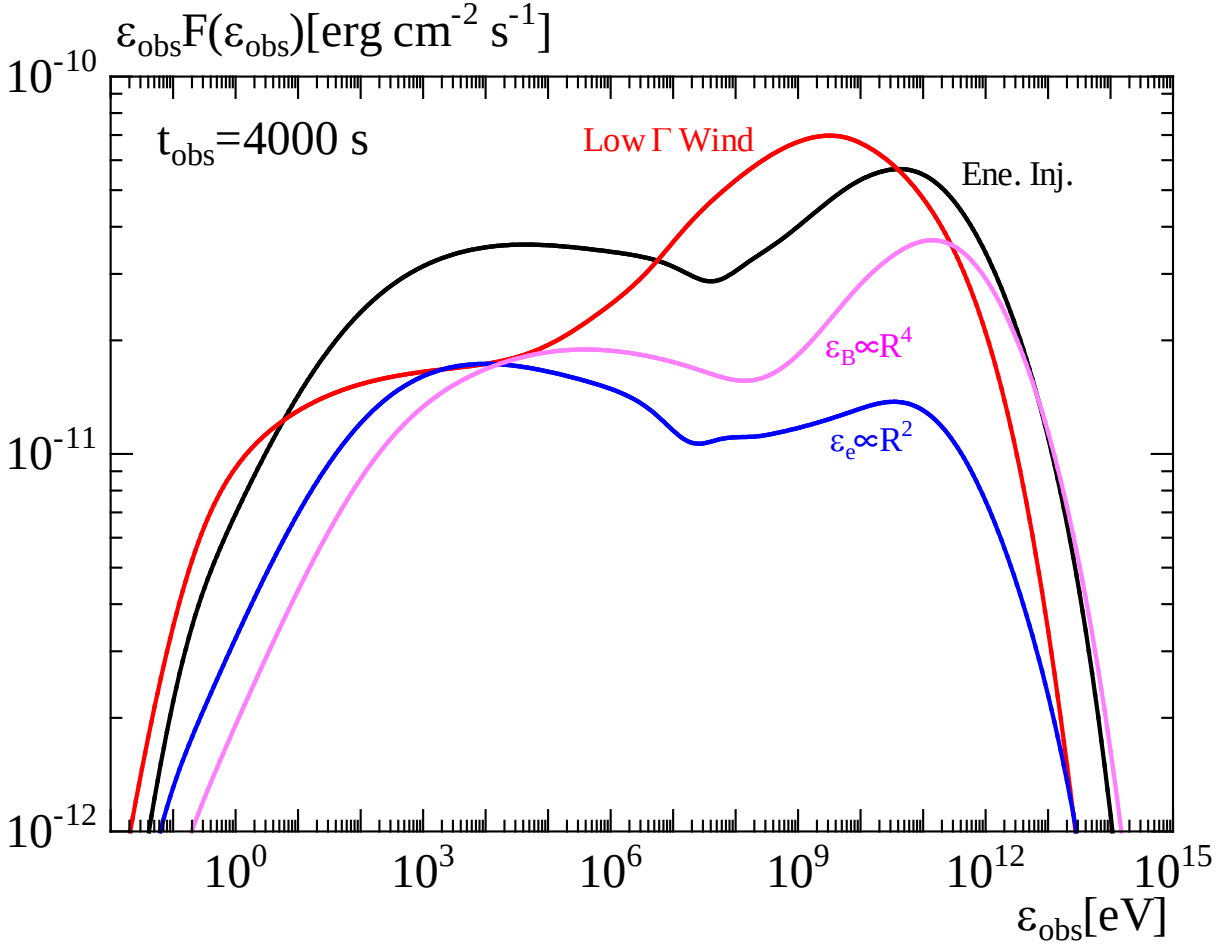


100 MeV

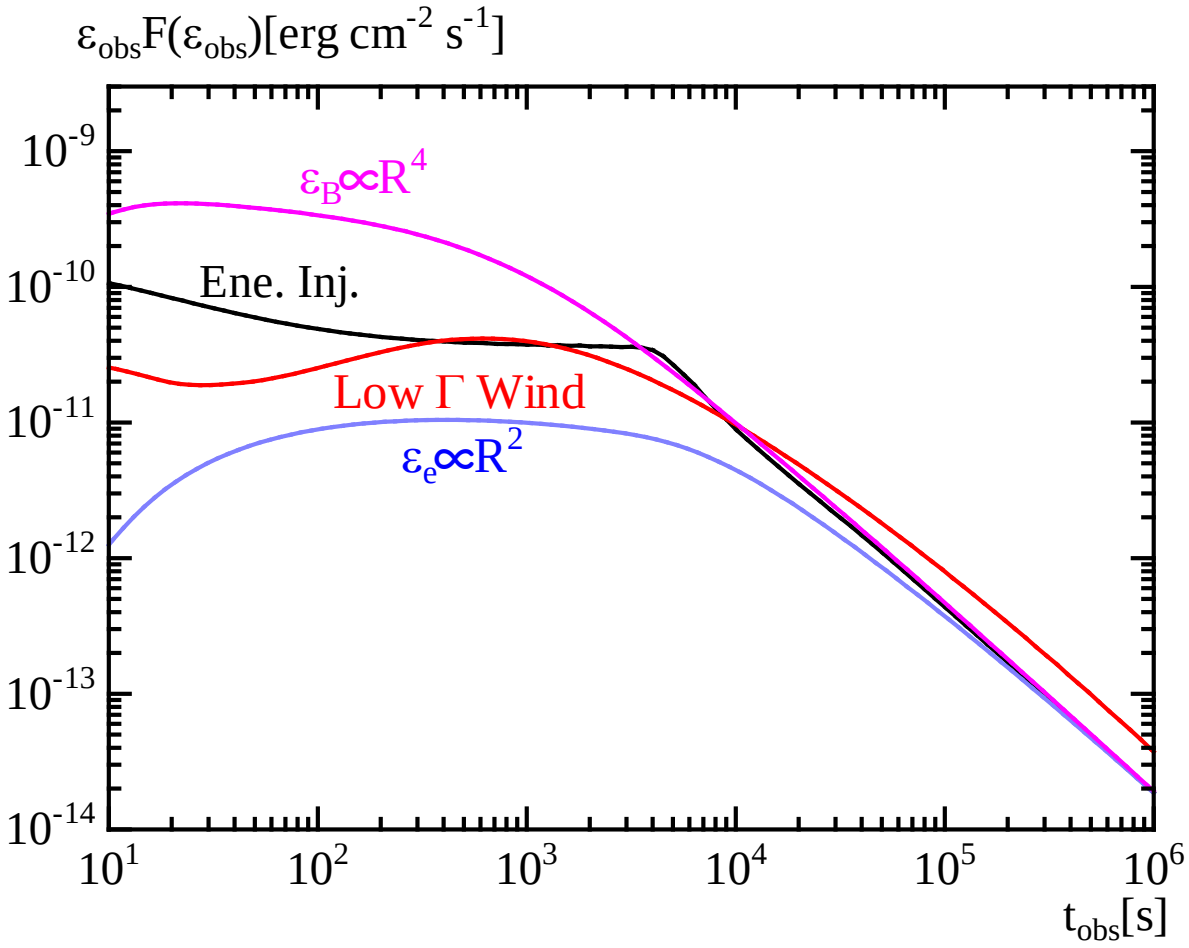


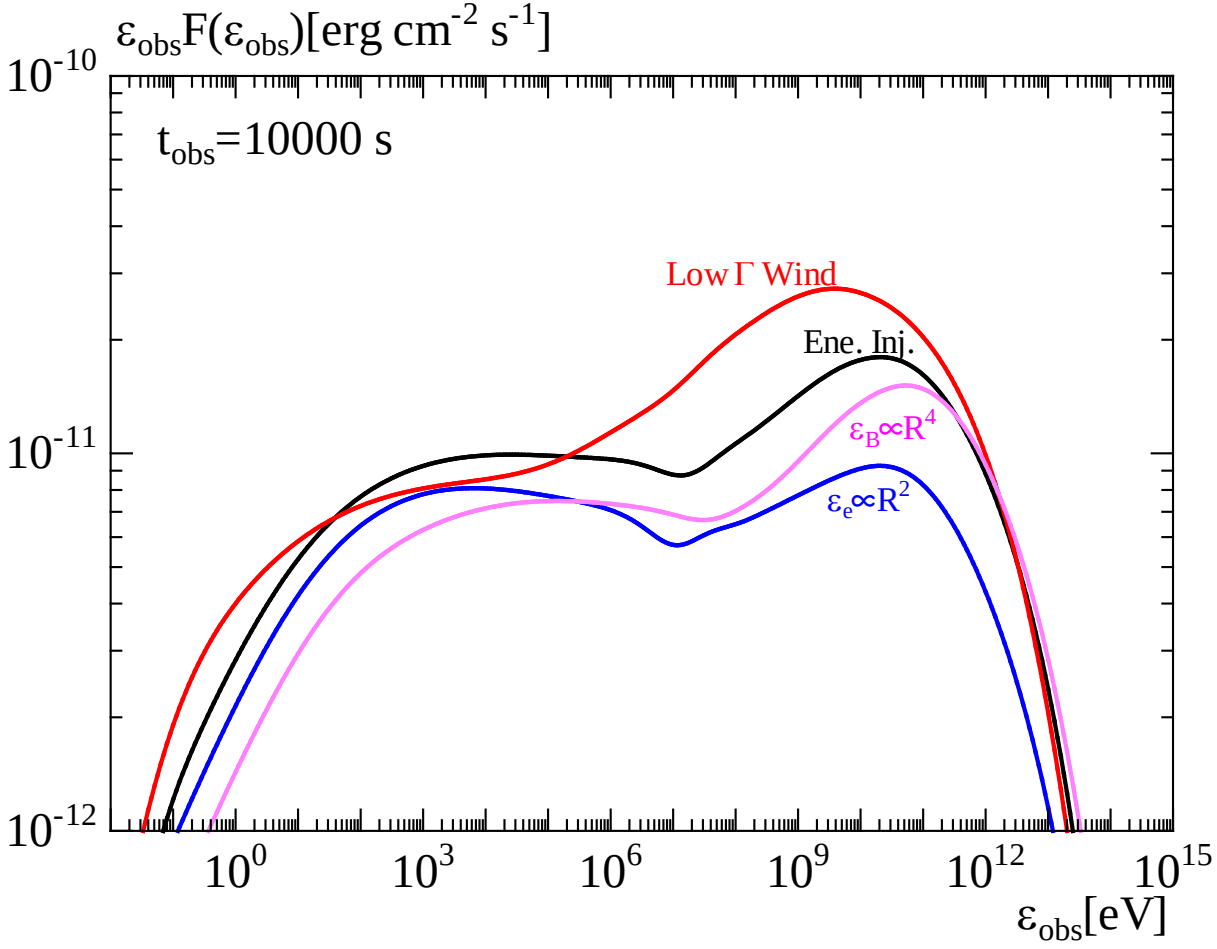
TeV Lightcurves



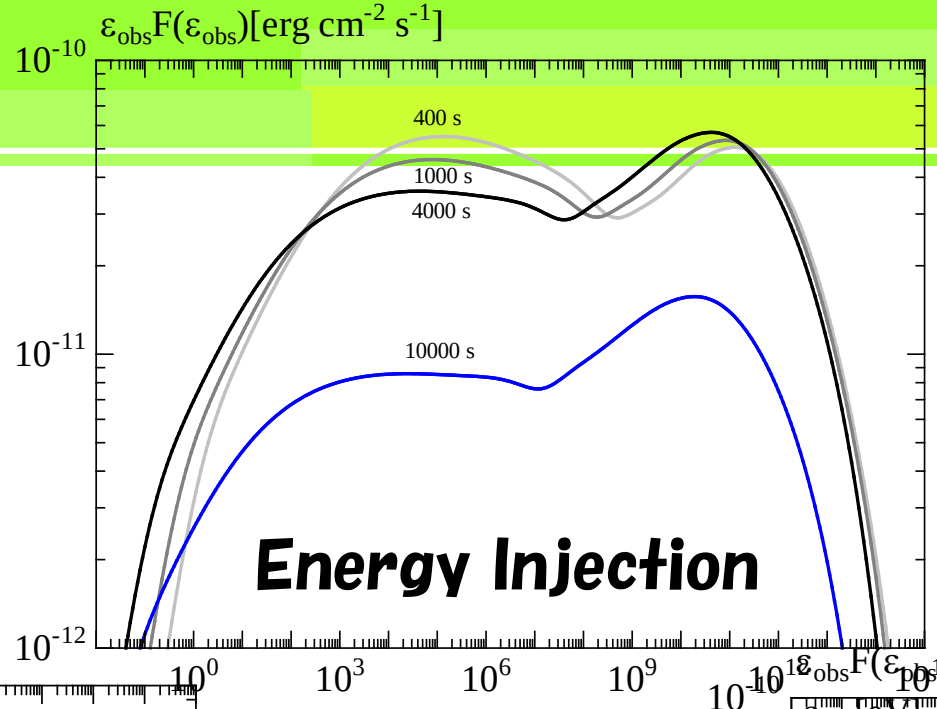


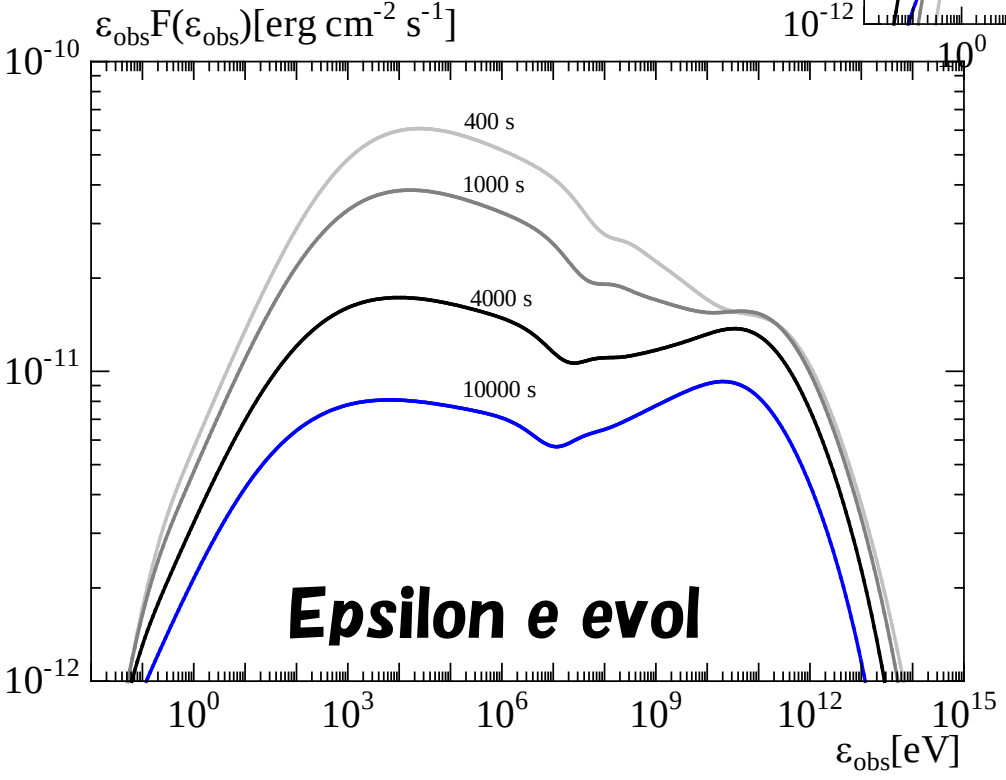
TeV Lightcurves

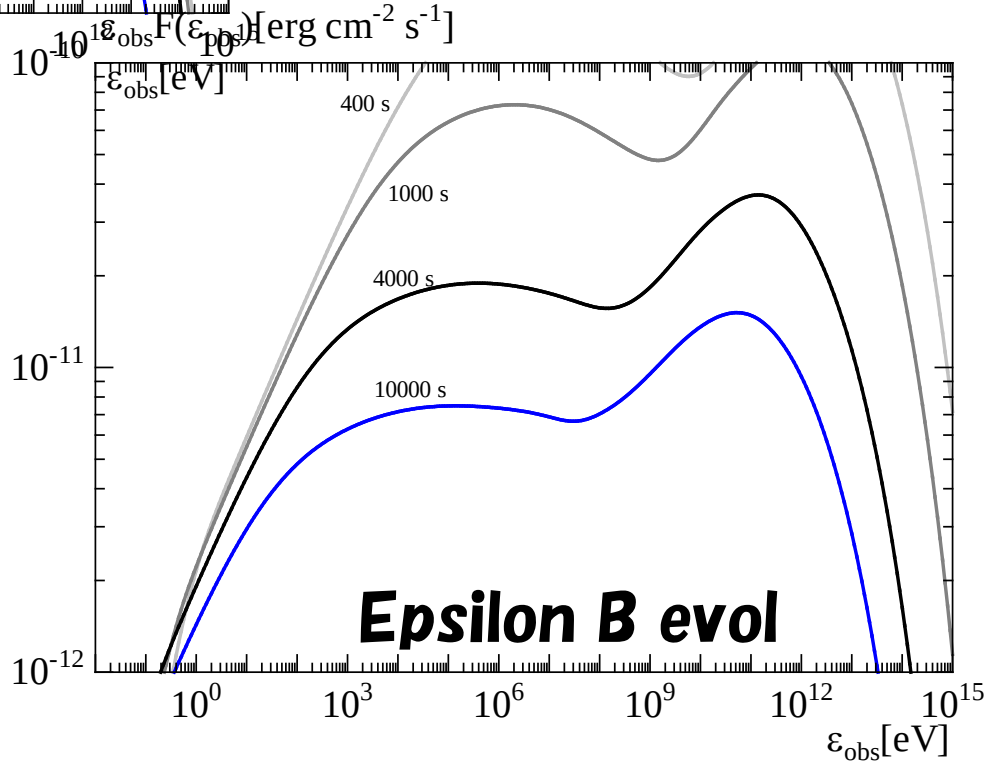




Spectral evolution







Summary

- Several models are possible for shallow decay phase.
- Gamma-ray detection constrains model of shallow decay.
- Parameter evolution affects the spectrum.
- Initial Low-B leads to hard electron distribution.